THE

INTERMEDIATE TEXT-BOOK

OF

PHYSICAL SCIENCE.

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BY

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PREFACE.

Professor Huxley, in a speech delivered some time ago, suggested the idea of a text-book of Physical Science which should enable those who had not received a scientific training to acquire a general knowledge of the phenomena of the universe. Notwithstanding, therefore, the number of good text-books on physical science, it seemed that there was still room for another, which should occupy an *intermediate* position between the elementary class books used at schools and the more advanced text-books used at colleges and universities. Especially was a text-book needed which would explain the leading facts of science and the methods used in scientific research, without the aid of mathematical formulæ.

In undertaking this work, at the request of the publishers, I have endeavoured to treat the various departments of science as parts of a connected system which is related at every point, and have arranged the order in which the subjects are looked at, so as to prevent as far as possible the anticipation of those which follow after. The difficulty has, however, been great, because the space which the scope of the work allowed for any one subject was so small that each paragraph required condensation to the utmost degree consistent with clearness, and even

knowledge will enlarge the range of the intellect, and open up a wide field of pleasure which might otherwise be closed; and even partial knowledge is better than none. It may also awaken in some minds a desire for further information, which may lead to the devotion of a lifetime to scientific research.

I have endeavoured to lay down *observation* and *experiment* as the sure foundation upon which all knowledge of nature and its laws must ever rest, and the work itself must therefore be regarded only as pointing out the direction in which these may be exercised by any who wish to obtain a personal knowledge of science; and the theories which are here given must be looked upon solely as helps to the mind in realising the nature of the operations which occur around us, and as liable at any time to give place to other theories which may more correctly interpret the phenomena.

The division of the work into parts is intended to enable like phenomena to be treated of together, and not to lead to the conclusion that they stand in a progressive order. While preparing this book I have had occasion to consult many admirable works on particular subjects, and for the sake of those who wish for further information the following may be named:—

Herschell's Essay on "Natural Philosophy," the late Prof. Stanley Jevons's "Principles of Science," Dr. Gore's "Art of Scientific Discovery," Whewell's "History of the Inductive Sciences," Ganot's "Physics," Deschanel's "Natural Philosophy," Herschell's "Astronomy," Ball's "Astronomy," Lockyer's "Elementary Lessons in Astronomy," Sir Edmund Beckett's "Astro-

nomy without Mathematics," Balfour Stewart's "Lessons in Elementary Physics," Silvanus Thompson's "Lessons in Electricity and Magnetism," Lee's "Acoustics, Light and Heat," Clerk Maxwell's "Theory of Heat" and "Electricity," Tyndall's "Heat as a Mode of Motion," Roscoe's "Chemistry," Cooke's "New Chemistry," Wurtz's "Atomic Theory," Tait's "Recent Advances in Physical Science," Balfour Stewart's "Conservation of Energy."

In many parts I have been obliged to employ technical terms, which teachers using the work as a class book must explain as they occur; but to facilitate its use without a teacher I have arranged that the index shall serve both as an index and a glossary, and the meaning of most of the technical terms will be found there.

In conclusion, I have to thank several friends for kind advice and assistance during the progress of the work. Edward Crossley, Esq., F.R.A.S., has been good enough to revise Part II., and Mr. William Ackroyd, F.I.C., Parts III. to VI.; and lastly, the whole of the proofs have been examined by the Rev. Dr. Harrison, of Waterfoot, whose revision, I have no doubt, has materially added to the value of the book.

F. H. BOWMAN.

WEST MOUNT, HALIFAX.

CONTENTS.

[*The numbers* (1), (2), *&c., refer to paragraphs which are numbered consecutively throughout the work.*]

Part I.

INTRODUCTION, INCLUDING METHODS OF INVESTIGATION, GENERAL PROPERTIES OF MATTER, AND LAWS OF MOTION.

CHAPTER I.

Definitions and Division of Sciences.

CHAPTER II.

Means of Investigation and Instruments Employed in Scientific Research.

Part III.

CONDITIONS OF MATTER—MATTER IN RELATION TO FORCE.

CHAPTER I.

Solids, including General Principles of Mechanics.

CHAPTER II.

Hydrostatics, including the General Properties of Liquids, at Rest and in Motion.

CHAPTER III.

Pneumatics, including the General Properties of Gases.

CHAPTER IV.

Acoustics, including the Nature and Laws of Sound.

Part IV.

CONDITIONS OF FORCE—FORCE IN RELATION TO MATTER.

CHAPTER I.

Light, including a Sketch of Physical Optics.

CHAPTER II.

Heat.

CHAPTER III.

Electricity.

Part V.

MOLECULAR PHYSICS, INCLUDING CHEMICAL PHYSICS AS A SPECIAL BRANCH.

CHAPTER I.

Compounds and Elements.

CHAPTER II.

Laws of Combining Proportion.

CHAPTER III.

The Atomic Theory.

Part VI.

THE CONSERVATION OF ENERGY.

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Part I.

INTRODUCTION:

INCLUDING METHODS OF INVESTIGATION, GENERAL PROPERTIES OF MATTER, AND LAWS OF MOTION.

CHAPTER I.

DEFINITIONS AND DIVISIONS OF PHYSICAL SCIENCE.

1. *Physical Science* is the systematised knowledge derived from observation of the phenomena which are exhibited in the physical universe, and of the laws which govern these phenomena. These phenomena are the manifestation of changes occurring in matter, or in the changed relationship of masses of matter, under the action of force. A *physical phenomenon* may therefore be regarded as any change whatever which, occurring in any matter, or in the relation of any two or more masses of matter to each other, can be made evident to the senses, either directly or through the agency of suitable instruments. As an example, we may take the fall of a body which can be seen with the eye, or the sound of a musical note which can be heard by the ear, or the sensation of heat or cold in any substance which can be detected by the touch, or a current of electricity

which reveals its existence by the motion of the magnetic needle, which may be placed in the vicinity of the wire in which the current is passing.

2. *The Cause* which underlies the changes which are produced by the action of force upon matter is called a *physical cause;* and the constant relationship which obtains or subsists between a physical phenomenon and its cause is called a *physical law.* Thus, when we speak of the law of gravitation, we refer to the constant attraction which subsists between any two masses of matter, and we express the numerical relations of this law by saying that the attraction varies directly as the mass of the body, or the total quantity of matter present in it, and inversely as the square of the distance between the two or more bodies which are attracting each other; or when we speak about the relation always subsisting between a ray of light which falls upon a plane surface and the ray which is reflected from it, we term this relation the law of reflection, and express it by saying that whatever may be the angle of incidence, the angle of reflection is always equal to it—the two angles being measured from an imaginary line drawn at right angles to the plane surface, at the point of incidence of the ray.

3. *Physical Laws* are the result of the constant action of energy upon matter, which energy manifests itself in special forms which we call *physical forces,* such as gravitation, heat, light, electricity, magnetism, &c. All these physical forces are mutually related, and are capable, under suitable conditions, of being transformed the one into the other.

4. *Forms of Matter.*—The different conditions which matter can assume under the action of energy are called *states,* or *forms of matter,* such as the *solid, liquid,* or *gaseous* state. Another state of matter, called "*radiant matter,*" is now known to exist, which far exceeds the gaseous state in tenuity, and may therefore be called also ultra-gaseous; and it is quite possible that if we could subject matter to the absolute zero of temperature, we

might also have an *ultra-solid* condition; but this has never been experimentally determined.

These different conditions of matter are the foundation on which depends our knowledge of the nature and properties of matter, and upon which our theories of the nature of matter, and the relationship of the various states to each other and to force, are based.

5. *Unity of Science.*—Strictly speaking, all physical science is one, because the universe as a whole is co-related in every part, and all its phenomena are therefore inter-related. The study of the universe as a whole might be termed *Cosmology*. For practical purposes, however, it is necessary to sub-divide the knowledge which we possess, because the mind cannot possibly grasp the whole of the phenomena and their relations when presented at once.

Hence arises the division of physical science into distinct branches, each of which investigates a special group of phenomena. Thus, *Astronomy* investigates the motions and nature of the planets and other heavenly bodies; *Geology* the structure and past history of the crust of the earth; and *Chemistry* the nature and properties of the various kinds of matter, and their reactions upon each other.

These separate branches of science are generally considered as distinct sciences, and as such, are usually treated of separately; but they are all related to each other, and every advance which is made by any one of them always leads to an increased knowledge in the others, and a broader base from which to start a further series of physical investigations in every department. Thus the discovery of spectrum analysis in Physical Optics has led to wonderful advances both in Astronomy and Chemistry; and the discovery of the delicate sensitiveness of the relation between electricity and magnetism has furnished instruments for physical investigation throughout the whole range of scientific inquiry.

In their greatest divergence, the relationship between

these various branches of science is sometimes difficult to trace. Thus, Astronomy and Botany are widely different in the phenomena which they register, but the relation of the two is distinctly seen when we remember how the astronomical changes produce the variation in the seasons, or the shorter alternations of day and night, with their consequent effect upon the vitality and growth of plants.

6. *Relation of Cause and Effect.*—The relation which subsists between all classes of physical phenomena and their cause is a quantitative relationship, and whenever this relationship can be thus determined, it can be subjected to mathematical as well as physical investigation. This quantitative relationship can only be derived from observation and experiment.

Observation and experiment are thus the foundation of all physical science, and no knowledge concerning the physical universe can be derived from *à priori* reasoning.

After observation and experiment have been made, mathematical analysis enables us to extend our knowledge of the phenomena and laws which govern them, within certain limits; but all our knowledge thus derived can only be regarded as theoretical until each new deduction has been verified by observation or experiment.

When the whole of the known laws relating to any special class of phenomena have been generalised, and subjected to mathematical analysis, so as to determine the nature of the relation between the cause and effect, they constitute what is called a *physical theory*. Thus we speak of the theory of gravitation in relation to the attraction which all masses of matter have upon each other; of the undulatory theory of light or sound, which regards these phenomena as vibrations of the ethereal medium and of air respectively; or of the mechanical theory of heat, which regards the temperature of bodies as the result of the peculiar motion of the molecules of which they are composed.

This method of extending our knowledge by the aid of mathematical processes is only applicable to certain sciences, because, while we can readily see how they can be applied to discover the position of a planet, by analysing the disturbing effect which is produced on the orbit of a neighbouring planet, this method cannot obviously be applied to determine the origin of species amongst animals or plants, or the nature of the successive appearances of life-forms in geological time.

7. *Divisions of Science.*—The various sciences may, therefore, be divided into two great divisions, which we term *Physico-Natural* and *Physico-Mathematical Sciences.*

Physico-Natural Sciences are those which depend upon observation alone, and where each step which is taken to advance our knowledge in regard to them must be derived solely from observation, and from such experiments as enable us to prolong our time for observation beyond that which would have occurred in the ordinary nature of things or course of events. In these sciences the relationship of cause and effect is not capable of quantitative determination, so as to bring the laws which govern it within the range of mathematical investigation, and thus enable our knowledge to be extended by this means. Here we may regard the laws as simply the observed sequence of phenomena. Under this great division we may range such sciences as *Geology*, *Physiology*, *Botany*, &c.

Physico-Mathematical Sciences are those where the changes observed are capable of numerical determination, and the laws underlying the phenomena can, therefore, be brought within the range of mathematical analysis and synthesis. This enables us to determine the phenomena which must occur as a necessary result, quite independent of all observation, under altered conditions of matter and force. Under this division we may class such sciences as *Astronomy*, *Mechanics*, *Hydrostatics*, *Electricity*, &c.

8. *The Physico-Mathematical* Sciences alone are

treated of in these pages, and they may be looked upon as really susceptible of division into two distinct classes:—

A.—Those sciences which investigate the nature and properties of matter in its various states or conditions, and its relation to the action of force;

B.—Those sciences which treat of the nature of force and its various manifestations, and of the relation of these various forces to matter.

Both of these classes of science are really the same investigations and phenomena viewed from different stand-points.

A.—In the first of these great divisions we study the nature and properties of matter as distinct from force, and the various changes which the matter undergoes when subjected to the action of force.

This division may be considered to include—

I. *Statical Physics*, which treats of the general properties of matter, such as extension, impenetrability, incompressibility, &c.

II. *Dynamical Physics*, which treats of the general laws which govern matter when in motion as a mass.

III. *Physical Astronomy*, which treats of the laws of motion, appearances, and physical constitution of the larger masses of matter of which the universe is composed.

IV. *Stereo-statics* and *Stereo-dynamics*, which treat of the general properties and laws of matter when in the solid state, at rest and in motion.

V. *Hydro-statics* and *Hydro-dynamics*, which treat of the properties and laws which govern matter in the liquid state when at rest and in motion.

VI. *Pneumatics*, which treats of the properties

and laws which govern the action of matter when in the gaseous state, either at rest or in motion. Under this head we also include *Acoustics*, which treats of the nature and laws of sound.

VII. *Molecular Physics*, which treats of the nature and laws which govern the combination and motions of the smallest masses of matter, and which may also include *Chemical Physics* as a special branch.

B.—In the second of these great divisions we study the nature of the energy which operates upon matter so as to change its condition, and investigate the various manifestations of force as they are revealed when derived from different sources of energy.

This division may be considered to include—

I. *Light*, its nature, properties, manifestations, method of generation, and the laws which govern its action upon matter.

II. *Heat*, with its two divisions of Thermo-statics and Thermo-dynamics, which include the nature, properties, method of generation, and laws which govern the action of heat upon matter.

III. *Electricity*, including Electro-statics and Electro-dynamics, which treat of the laws and phenomena of electricity, at rest and in motion. It includes, as special branches, Magnetism, Frictional Electricity, Voltaic Electricity, Animal Electricity, and Thermo-Electricity.

IV. *The Conservation of Energy*, which treats of the correlation of force, and the transmutation of energy into its various forms or modes.

9. *Natural Philosophy.*—The whole of these subjects, when taken together in both divisions, may be regarded

as constituting a complete course of *Natural Philosophy*. Before, however, we can profitably study the various sciences separately, it is necessary that we should look shortly at some of the means which are employed in the investigation of natural phenomena, and some of the instruments which are used to supplement the narrow range within which our senses can operate, so as to receive the impressions of the nature and structure of matter, and the changes which are constantly occurring in it, as well as the means of detecting the various forms of force.

CHAPTER II.

MEANS OF INVESTIGATION AND INSTRUMENTS EMPLOYED IN SCIENTIFIC RESEARCH.

10. *Foundation of Physical Science.*—As we have already seen, the foundation of all physical science is observation and experiment, and nothing can be determined in regard to natural phenomena from any *à priori* considerations whatever. All our knowledge must rest solely upon observation and experiment, or upon mathematical deductions which arise from results already furnished in this manner; and just in proportion as this great and fundamental principle has been acknowledged and acted upon has the progress of physical science been accelerated or retarded.

Notwithstanding this, however, there are other regions or departments of knowledge which have an important bearing upon the study of physical science, and without an acquaintance with which it is quite impossible to prosecute physical inquiry with any degree of success.

It is necessary, therefore, to look shortly at some of

these departments of knowledge, so as to enable us to appreciate their bearing upon physical science, and understand the important service which they render to it. They may be termed *Pure or Abstract Science*, so as to distinguish them from the physical sciences which we are considering.

11. *Pure or Abstract Science* differs from physical science fundamentally in this respect: that while the latter is based upon observation and experiment, the former is quite independent of either. We have a good instance of abstract science in Geometry or Mathematics, where the whole structure of the science and its fundamental axioms are the result of pure reason, and take their origin entirely within the mind alone, and altogether apart from any external considerations. Abstract science is, indeed, quite independent of any system of nature or creation, and its necessary conclusions hold good everywhere and throughout all time. It deals, in fact, with existences and the relations of existences, which we cannot conceive not to *be* by any mental or physical process whatever, and which form the substratum upon which rests all our fundamental notions of *being*, as distinguished from *non-being*, or *nothing*. As an example of these inherent ideas, we may name time, space, order or sequence, number, &c.

These are what we may term necessary truths, and are quite independent of any cause. Indeed, into abstract science the notion of cause does not enter, and the truths are quite irrespective of anything which may represent them. As an example, we may take any of our geometrical ideas. There may be no such thing as an actual circle marked out in space, and with our definitions of lines and points, as length without breadth, and position without magnitude, there could be no such thing drawn; but if we once imagine it to be so, we are obliged to admit that all parts of the circumference are equi-distant from the centre, and therefore all the radii which can possibly be drawn—and they are infinite—

must all be equal. In the same way, all the triangles drawn within a semi-circle, the one side of which is the diameter or chord of the arc, and the apex any point in the circumference of the circle, are all right-angled triangles. Whatever size the circles may be, or wherever drawn on a plane surface, they must always yield exactly similar results; and we can assign no cause for it, since it is the necessary result of the very idea itself.

This independence of all external things renders it possible to discover all the axioms and propositions and laws of abstract science, such as Geometry, without the aid of a single observation or the performance of a single experiment; although it will be readily seen that the results arrived at by pure reason may be, as in Practical Geometry, strengthened and confirmed by the sensible delineation of the circles and triangles, and the measurement of their relations: the truth of the propositions being, however, quite evident to the reason without such experimental proof.

12. *Symbolic Forms of Thought.*—Along with these fundamental ideas there also follows, as a secondary consideration, the nature and laws of the forms or symbols in which we embody our ideas of the nature and relations of these notions. We may consider these as including:—

1. *Language*, whether existing in thought, spoken or written. This language we may consider to individualise being, and thus enable us to distinguish between one idea and another, or one thing and another. Without such distinction, it is obviously impossible either to think or reason at all. Along with language we may also consider to be embodied the necessary laws or rules of language in regard to things, which constitute grammar, and thus prevent confusion in regard to gender, number, case, tense, &c.
2. *Logic*, which embraces the nature and relations of the laws of thought, because we cannot think

except according to a definite order, if we are to think correctly: that is, so as to arrive at truth as a result. Any other method of thought except the right one invariably leads either to wrong conclusions or else to confusion. We may also consider Logic as the science of relations which are qualitative, as distinguished from Mathematics, which treats of relations which are quantitative. This logical process may be divided into two different branches: viz., *Formal Logic*, which investigates the harmony of thought with its own necessary conditions; and *Applied Logic*, or *Metaphysics*, which deals with the relation of formal thought to external being or the nature of things.

3. *Notation*, or the *Calculus of Number*, or the figures or symbols in which our ideas of number and its relations are embodied, and which is included under the general term of *Mathematics*. When this calculus relates to our ideas of abstract quantity, and the harmony of number with its own necessary laws, we term it *Algebra;* or when the idea of space is introduced, *Geometry*. When these notions are concrete or individualised, so as to enable us to apply our laws and theorems to specific cases, we term it *Arithmetic*. All these fundamental ideas, as we have already said, are such that we cannot think or conceive of their abstract nature being different from what it is; but we can, however, conceive of our artificial forms or symbols, in which we embody these fundamental ideas so as to make them intelligible to our thoughts, being different. Thus we know that the same things have different names in the different languages of mankind, and the symbols of Algebra might be infinitely varied. In Arithmetic, we might not only have an entirely different notation, but also the scale of the system might be twelve, or any

other number, instead of ten, as in the ordinary scale; and yet we should be able, with equal accuracy, to perform all our operations and arrive at the same results.

13. *The Laws and Principles of Abstract Science* underlie all our ideas of physical science, and, indeed, so much is this the case that, although we cannot obtain any knowledge of natural phenomena, or the laws which govern them, without observation or experiment, still, if we find the results of these observations or experiments to contradict any of the laws or principles of abstract science, we should feel quite satisfied that our observations had been erroneous, and that our experiments had not been conducted with the accuracy necessary to secure a correct result.

It is quite essential, therefore, for all who wish to pursue physical science to its highest limits, and to acquire an accurate knowledge of it, to have the mind thoroughly trained in the principles and methods of abstract science, by which alone the reason and judgment can be so exercised and disciplined as to enable them to detect all the errors which can creep into our observations and experiments. This training and knowledge are also absolutely necessary in order that we may analyse the results of the knowledge which we thus obtain, so as to deduce the laws which underlie the phenomena, and predict or determine the consequences or results which must flow from them. As an example, observation enables us to determine the relative positions of the heavenly bodies, and the paths in which they apparently move; but abstract science alone can analyse these positions and motions, and determine, from the condition of things in the present, the positions which they will occupy, and the paths in which they will move in the remote future, or, with equal certainty, what must have been the relation of their positions and motions in the remote past.

Experiment may enable us to determine the quantity of heat which is necessary to expand a given volume of gas

to any definite degree under given conditions of temperature and pressure; but abstract science alone can enable us to analyse the results of the observations, so as to enable us to frame a definite conception of the nature of the work performed by the heat, and the effects which it would produce under altered conditions, such as pressure in relation to a constant volume when subjected to different degrees of heat.

14. *Observation and Reason.*—Unless the indications which are given by the senses are corrected and interpreted by the reason, they would frequently lead to the most false conclusions, but when the two are made to correct each other, and thus work in unison, they enable man to unlock the most secret recesses of nature, and enrich the mind with illimitable stores of knowledge. Thus, the science of Astronomy is entirely based upon observation, and these observations during the earliest ages revealed many anomalies, such as the retrogression of the planets, which seemed inexplicable to the reason; but as soon as it was discovered that the motions of the planets traced out paths in space which could be investigated by Geometry, and which possessed geometrical relations to each other, the progress became rapid, and advanced within the limits of a single life-time more than it had done during all the previous ages during which the science had been cultivated, while the anomalistic motions were all explained, and proved to be the necessary result of the various speeds with which the different planets moved, and the relations of their orbits to each other.

The early progress of Astronomy was also retarded by the endeavour to make abstract reason supply the place of observation; and many of the absurd notions of the ancients—such as that there could only be seven planets because seven was considered the perfect number, or, that the planets must move in circles, rather than ellipses, because the circular was supposed to be the perfect motion—could easily have been corrected if they would have observed more and reasoned less.

It cannot, indeed, be too strongly affirmed that reason and observation must go hand in hand—each in due subordination to the other—discriminating those cases where the one or the other is to have the predominance, and always checking the results derived in the sphere of the one by those derived in that of the other.

15. *Cause and Effect.*—We have already said that in the domain of abstract science the idea of cause has no place. We cannot, for example, conceive of a cause why the sum of three angles of every plane triangle are together equal to two right angles, or why all the diameters of an ellipse are always bisected in its centre. The very essence of all physical science, however, is the search after, and the determination of, *a cause*, and just in proportion as our knowledge of physical causes is widened or extended, we are able to arrive at more extensive generalisations of knowledge—to see more clearly the relations which underlie all the phenomena of the universe, and link them together in one harmonious whole. For example, the varied phenomena exhibited by the reaction of matter and light upon each other, such as refraction, diffraction, interference, polarisation, and the like, are a series of isolated phenomena until we consider them as the result of a common cause—which is the vibration of an ethereal medium—when we can not only see the harmonious relation between them, but predict, as a result of this cause, a whole series of other phenomena which have been exactly confirmed by experiment.

16. *Numerical Relation.*—In the study of physical science also we not only investigate the nature of the cause which underlies the phenomena, but also the exact relationship, numerically and otherwise, in which the two stand to each other, and we never rest satisfied with any investigations which do not reveal to us a sufficient reason why any given cause produces a given effect.

To do this effectually, as we have already seen, demands a wide acquaintance with the pure sciences, such as *mathematics* or geometry; and without this prelimi-

nary knowledge no inquirers can ever rationally expect to attain to such a position as will enable them to possess a full and intimate sense of the nature and validity of the evidence upon which the scientific demonstration of the laws of natural philosophy rests. To such the inner doors of the great temple of nature will ever be closed, but they may, nevertheless, attain to a considerable knowledge of the results which science has demonstrated, and although incapable of following out the various steps in the process by which the laws and their verification are determined, they may be enabled to understand the principles upon which the demonstration is founded, because they are in unison with those processes of thought and reason which are in use in the ordinary affairs of life. The conviction of the truth of scientific methods and inductions will also to such be materially increased and strengthened by the many instances, which are daily occurring, of scientific prediction or foreknowledge of phenomena, such as the occurrence of eclipses at the stated time, or the return of a comet after the interval of a century.

It is thus possible to look at the whole range of physical science from a standpoint which is not mathematical, and to acquire a very considerable knowledge in regard to all the various branches into which such science is divided, as well as the fundamental principles upon which physical investigation depends, without any other preliminary training than that which is demanded by the rudiments of an ordinary education, and a fair acquaintance with the common rules of arithmetic.

In order to do this, however, it is also necessary to possess some knowledge of the nature of the methods of procedure which are followed in scientific inquiry, so as to enable the mind to rest assured that these methods are likely to lead to, and are sufficient to secure, the results which are claimed for them.

17. *Observation and Experiment.*—We have already said that observation and experiment form the founda-

tion of all scientific inquiry, and there is a sense in which we may regard both these methods or operations as one in kind, and differing only in degree.

Observation is the recording of facts as they occur, and the conditions under which, as well as the frequency with which their occurrence takes place, so as to obtain a record of the nature or character of the phenomena as a basis upon which to reason and generalise.

Experiment is the subjection of the facts of observation to successive recurrence, under conditions in which the observation can be more advantageously and continuously exercised; and may also embrace the alteration of the conditions under which the phenomena occur, so as to enable the alterations which are produced by such changes in the phenomena to be more effectually observed. Observation may be regarded as applying more strictly to the perception of phenomena without any endeavour to alter the course of events, and with the single desire to record, either in the mind or otherwise, the phases and sequence of phenomena; while experiment has as its ultimate object the verification of the facts of observation, so as to remove any grounds of uncertainty in regard to the real nature and sequence of the phenomena which have been observed. Experiment thus enables us to detect sources of error which arise from defective observation, as well as to continue our observation during a longer period of time, or with more frequent recurrence than in the ordinary processes of nature. For example, nothing can be more strictly an act of observation than the attitude of the astronomer when watching the transit of the planet Venus across the surface of the sun, so as to obtain the means of determining the solar parallax; and as this event only occurs at long intervals of time, and the period of contact at ingress and egress only lasts for a fraction of a second of time, it has been found much too short to notice all the phenomena which occur at the moment, and considerable discrepancies in determining the times of contact have always arisen, from

different observers noting different phenomena. It was not, indeed, until a method was discovered by which an artificial transit could be produced, which could be made to occur as often as desired, by means of a model which permitted a dark disc to cross over a circular luminous surface which represents the sun, so that continual observation could be made beforehand, and all the phenomena and conditions which would occur at the moment be repeatedly observed, that the desired accuracy was attained which secured accordance amongst the observers of all nations who were to be employed in the Transit Expeditions.

In the same way we should have known very little of the real nature and manner of the electric discharge, as exemplified in a flash of lightning, which only lasts for a small fraction of a second of time, and the position of whose recurrence none can accurately determine, if we had not discovered means by which the discharge can be artificially produced, with any desired frequency and intensity, and thus enabled it to be subjected to not only continuous observation but also to variation in the conditions under which it occurs.

Observation and experiment may be regarded indeed as passive and active observation, and are thus the two pillars upon which physical science rests, and together form the means by which we gain experience, which is indeed the great and only ultimate source of our knowledge of nature and its laws.

18. *Accuracy in Observation.*—From this it will be seen that the utmost importance must be attached to accuracy of observation and experiment, because, unless our facts which can only be derived from observation are true, and our experiments correctly performed, so as to enable us to cross-question the facts and thus test their accuracy, as well as gain additional knowledge in regard to them, we can never attain a true knowledge of them, either with respect to the phenomena themselves or their cause.

Accuracy in observation depends upon :—

I. Strict conscientiousness.
II. Mental fitness.
III. External or sensuous fitness.
IV. Instrumental fitness.

19. (I.) *Conscientiousness.*—At first sight it might seem that conscience did not enter as an element into physical observation, but a very little reflection will show that it lies at the very base of all true observation; because, as a very first essential, there must be the determination to accept nothing as fact which is not such, to neither add to nor subtract from the observed phenomena, nor in any way permit the mind to alter or vary the sequence of events, so as to record them as other than what they really are.

This inherent love of truth, for its own sake, has always been a prime characteristic of all who have been the great pioneers and discoverers in natural philosophy, and without it no forward steps can ever be taken. This remark applies to every act of observation and experiment in whatever department of research it is made, and to all the numerical or analytical processes which are founded upon the results so obtained. Any experience founded upon unconscientious observation is certain to be fallacious, and cannot be of any service either to the person who makes the observations, or to any who may afterwards use them. It is, indeed, the very reverse, for it becomes a source of error which may run through many generations, and entail an immense amount of work upon those who find that the incorrect observations contradict those which they have obtained, and thus the progress of science may be retarded rather than advanced.

20. (II.) *Mental Fitness.*—Strict conscientiousness cannot, however, take the place of mental fitness, and it is not too much to say, that all minds are, more or less, unfitted in some way or other for correct observation and experiment. The character, temperament, feelings, and mental state of the observer are always elements which

are apt to interfere with the correctness of observation, even when there is every desire to obtain nothing but the truth, and record nothing but the facts of the case.

Every observer has what is known as a personal error, and, with the utmost desire for fidelity in observing or recording, this personal equation introduces inaccuracy. So true is this, that Lord Bacon observed that the human mind was constituted like an uneven mirror, and thus rendered incapable of reflecting the events of nature without distortion. Most men, for example, anticipate and see an expected event, such as the transit of a star before it really occurs; and it is always necessary, in every series of experiments, to determine, if possible, the character and temperament of the observer, so as to estimate the probability and the nature of the errors which he may have unintentionally made.

In addition to this personal error, there is always the difficulty created by pre-conceived notions, arising from education or otherwise, of what ought to be, and the tendency to make the facts of observation support special theories which the observer has the desire to establish, and which bias the judgment so as to render it incapable of forming a right estimate of what is really the fact. So much so is this the case, that for exact results to be obtained it is sometimes necessary to employ entirely disinterested observers and computers, who can have no possible desire to make the observed phenomena, or the deductions from them, other than what they exactly are.

We frequently see this unconscious bias in ordinary life, in the different values which are put upon the same object by two different persons, who have every desire to be correct, but who have a personal interest in the matter, when compared with the value which will be given by an independent assessor.

In addition to this there is the fact that some minds are not capable of correct observation, arising from some defect in the mental constitution; but all minds are susceptible of education, so as to improve the original

faculties. Few men are, however, like Professor Faraday, whose mind seemed to possess the power of both passive and active observation in its highest degree, and to such a mind education is much easier than under ordinary circumstances.

Like every other faculty, that of observation becomes sharpened by use, and a thorough training is always necessary to secure the power of observation in its most accurate form.

True observation and experiment can only be conducted, as a rule, by those who know the nature of the work in which they are engaged, and who can, therefore, tell what to look for, and which parts of the transpiring phenomena are of most importance and really bear upon the investigations in hand.

The perfect observer and experimentalist must, indeed, possess many qualifications, such as quickness of perception, judicial calmness of mind, an unexcitable temperament, freedom from mental bias, and a retentive memory. Professor Jevons asserts that the successful investigator must combine diverse qualities. "He must have clear notions of the results which he expects, and confidence in the truth of his theories; and yet he must have the candour and flexibility of mind which will enable him to accept unfavourable results, and abandon mistaken views."

21. (III.) *External or Sensuous Fitness.*—Whatever conscientiousness or mental fitness, however, the observer may possess, there is always the necessary difficulty arising from the material condition of the body in which the mind is enshrined.

All our knowledge of external nature is communicated to the mind through the organs of sense, and even supposing that these were all perfect within their range, there is still the fact that their range is extremely limited, and that there are whole series of phenomena which cannot be rendered evident to them except as a secondary effect. As an example, we have no sense which can

detect polarised light from ordinary light, or distinguish magnetic phenomena.

We all know, moreover, that the senses are not unfrequently very defective. Few persons have perfect sight or hearing; and, indeed, even when the sight is good, so far as the perception of the external forms of objects is concerned, the power to discriminate differences in colour varies very much in different individuals, and also at different times in the same individual. One person in every fourteen is more or less colour blind; and most people are aware how much more frequent is defective sight, so far as perfect distinctness is concerned, either at short or long ranges. In addition to this, the limit of the power of the senses is confined within a very narrow range. Thus, with regard both to the eye and the ear, which are acted upon by luminous and sonorous vibrations, a certain number of impulses in a given time are necessary before these organs can receive any excitement which can be transmitted to the brain, and whenever the impulses exceed a given number, the power to receive the sensation ceases.

The range of the eye is from red to violet light, which corresponds to a wave length of from $\frac{1}{37,000}$th to $\frac{1}{60,000}$th of an inch, and from about 458 to 727 millions of millions of vibrations in a second, and beyond this range on both sides, above and below these numbers, the eye is quite insensible to the sensation of light, although we know that there are vibrations of the ethereal medium beyond both these. The ear commences to act with a wave length of about $1\frac{1}{3}$ inches, and ends when a 32 feet wave length is reached, and the number of impulses falling upon the ear per second corresponds respectively to about 8,192 and 32—the longest vibrations in length and time corresponding to the deepest notes.

Taste, and smell, and touch are also very limited in their range, and all must have observed, in regard to the senses, how very untrustworthy they are in regard to exact or numerical determination. How few can determine

the size or length of a body by the eye alone without any other measurement. Ask a number of individuals the apparent size of the sun, and all answers will probably be given from about six inches in diameter up to three feet, while the real apparent size is only about that of a fourpenny piece, seen at ten inches' distance, or about $\frac{5}{8}$th of an inch. How few can determine the temperature of water by the use of the hand or the foot alone; and, indeed, without the aid of a thermometer, or some such means, all quantitative determination of temperature would be at an end, for how very frequently one person feels hot at the same temperature as another feels cold.

In addition to this inaccuracy of determination, the range in nature, within which the senses operate, is also small. Accurate vision soon becomes impossible at a comparatively short distance, and we should know nothing of the physical constitution of the sun or planets, or the glory of the midnight heavens, with the naked eye alone; while beneath and below all that the unaided vision can discern, there is a universe of the infinitely little which would have remained for ever unknown to man but for the invention of the microscope. So, too, with the other senses, such as taste, or smell, or sound, or the sensation of heat—how soon we pass the limits within which they can act. For example, no sense of difference in the degree of cold or heat can be determined by the unaided senses, with any degree of exactness, when the cold is much below the freezing point, or the heat above about 180° Fahr.

What can be learned, indeed, of the universe by the aid of the senses alone, forms only the lower limit of our knowledge and beyond this there lies a boundless region, where the unaided senses can never penetrate.

Accuracy of observation—so far as the senses are concerned—therefore, is almost unattainable, and it requires the utmost care to prevent the various sources of error which are thus liable to arise, either in passive or active observation, from interfering with the accuracy

of the results. The evidence of our senses, indeed, requires to be tested and cross-questioned at every step, and continually corrected by the exercise of the reason before the observations can be recorded.

It is also essential that all observations should be made, as far as possible, under conditions in which the senses are best fitted to receive correct impressions. The body should not either be fatigued or excited, and the conditions, whenever possible, should be such as to secure comfort in observation, which will prevent the distraction of the mind. Care should also be taken, especially in experimental observation, where the circumstances are usually more under control, to arrange the experiments in such a manner that the special sense which shall be called into play by the experiment shall be placed in the best position for observation.

Just as the faculties of the mind can be rendered more acute and trustworthy by cultivation and exercise, so in the same manner the range and power of the senses can be improved and extended. Use becomes second nature, and latent powers become developed, which enable even those who have not been gifted originally with great accuracy of perception to enormously increase their efficiency. Thus the educated eye can detect differences of form or shades of colour which are quite indiscernible to an untrained eye; and the ear of the musician can distinguish variations in tone and subtle depths of harmony which evade detection by the uneducated ear.

22. (IV.) *Instrumental Fitness.*—No education, however, can increase the power of the senses beyond a certain point, and when this is reached, it becomes necessary to supplement them by the introduction of artificial means. The progress of scientific discovery and the improvement in the mechanical arts have enabled this to be done with a success and to an extent which is absolutely marvellous. Almost every new discovery in physics has furnished science with a new instrument to aid in further scientific investigations, and every new refinement which has been

introduced into the mechanical arts has enabled still greater instrumental range and accuracy to be attained. This has in its turn re-acted upon the progress of science, and enabled it to advance still farther.

We may look at these instrumental aids in connection with the various senses of which they increase the range and accuracy :—

(*a*) Instruments which aid the eye.
(*b*) Instruments which aid the ear.
(*c*) Instruments which aid the taste and smell.
(*d*) Instruments which increase the range of feeling with regard to temperature, &c.

23. (*a*) *The Eye* is essentially an optical instrument —an arrangement of lenses which are capable of adjustment to meet the requirements of difference in distance and in intensity of light. These lenses converge the rays of light, which proceed from all luminous bodies, and concentrate them upon the living screen or retina, where the image of the object is formed, and which is in nervous connection with the brain. The eye judges of distance by the degree of convergence of the rays, the most distant objects subtending the smallest angle. All optical instruments are formed upon the same principle, with adjustments for similar purposes, and using the retina of the eye of the observer as the screen upon which the image is thrown, except in those cases where photographic registration is desired, in which case a chemically-prepared surface is used instead.

The Telescope, whether reflecting or refracting, is only an artificial eye, which presents a far larger area to the luminous rays, and thus concentrates into a small space, and renders visible the impressions which could not be discerned by the smaller quantity of light which falls upon the area of the external eye. It increases the range of the eye almost beyond belief. To the naked eye the number of stars visible in the vault of heaven are to be counted only by thousands, but with the telescope literally *by millions*. The almost imperceptible discs of the planets

become broad and pictured surfaces, where the very clouds which float around the poles and the equator are distinctly visible, and the numerous moons which attend some of them can be clearly seen. Distant objects, indeed, assume a distinctness only limited by the nature of the refracting or reflecting medium and the condition of the intervening space, so that terrestrial objects may be viewed as if close at hand, and even the surface of the moon as if only forty miles distant.

What the telescope has done for distance the microscope has accomplished for minute objects.

The Microscope is really a telescope reversed, in which the image of the small object, seen under brilliant light, is projected into the eye in such a manner that it subtends a large angle, and thus appears close at hand. The naked eye can hardly discern the $\frac{1}{100}$th of a linear inch; but the microscope enables the observer to detect divisions up to the limit of human vision, which varies in different individuals from the $\frac{1}{80,000}$th to the $\frac{1}{140,000}$th of a linear inch or thereabout. Nor is this all, for both the telescope and microscope are capable of being made into instruments of precision which enable angular and numerical registration to be made, which would be absolutely impossible without mechanical aid. The two instruments, indeed, mutually aid each other. The equatorial mounting of the telescope enables the motion of the earth to be neutralised, and thus the observer can look at the surfaces of the sun and planets as if they were at rest instead of moving in the heavens. The graduation of the divided circles which measure the angles of position can, by means of the vernier and microscope, be made to give results of astonishing accuracy. With a modification of the microscope micrometers can be constructed, which, when introduced into the eye-piece of the telescope, render it possible to determine the value of small arcs which cannot be arrived at by the larger circles. When the *Micrometer* is associated with the microscope we possess an instrument for determining the value of small

distances, the range of which is only limited by the power of the human eye to receive impressions upon the retina.

The same optical principles can be and are introduced into the construction of all other instruments used in physical research, and many of these enable us to obtain results both in observation and registration which without them would be absolutely impossible. By means of a small mirror which reflects a beam of light thrown upon it, and which beam is reflected into a graduated scale placed at a distance from the mirror, we can multiply small angular deviations in the mirror to almost any extent. When such a mirror is attached to the moving parts of our instruments for the detection of electrical and magnetic disturbances, we possess a range of power which far exceeds anything which could be attained by the use of the unaided senses, however much they might have been educated.

We may also mention here the various instruments which measure and record the flight of time, so as to render it visible to the eye, such as astronomical clocks, chronometers, and chronographs of different construction, which are amongst the most perfect of machines, and which enable the duration of phenomena to be seen or recorded to the most minute fraction of a second.

Such instruments may also be mentioned as theodolites, levels, barometers, and various kinds of pressure and other gauges, which enable us to determine alterations in the action of molecular and other forces, either in a visible or graphic manner, and thus to study these changes with greater facility.

24. (*b*) *The Ear.*—The limited range of the ear is also enormously increased by the aid of instruments such as the microphone and telephone, by means of which the very faintest sounds, such as the noise made by the motion of the feet or the respiration of a fly placed upon the microphone box can be rendered evident to the ear, and even be transmitted to a very great distance. The

application of electricity to the construction of instruments for aiding the ear indeed opens out an entirely new field for research, and is already prolific in results which cannot but end in many important discoveries. These instruments are already being applied to physiological research with singular success, and will doubtless enable minute physical changes which are accompanied by the emission of sound to be studied in a manner which, without them, would have been quite impossible.

25. (*c*) *The Taste and Smell* are usually employed to detect differences in the real nature of the materials which arise from variation in the chemical composition of the substances. By them we can determine whether the various substances examined are bitter or sweet, acid or alkaline, or whether they are volatile, and thus diffused as a gas through the atmosphere, where they reveal their presence by their characteristic odour. Although we can scarcely say that instrumental aid has been afforded to these senses by direct mechanical means, still the progress of chemical science has enabled us to employ agents for the detection of these differences, which far exceed in delicacy the most acute and educated senses. Thus a tincture of litmus will decide whether a liquid is acid or alkaline, when the proportion of either present is far too small to be appreciated by the tongue; and the presence of even gases which possess a powerful smell, such as sulphuretted hydrogen or chlorine, can be detected by chemical means in quantities which are far too much diffused to be rendered evident to the smell. The whole of the senses, indeed, which can be called into play in order to detect the difference in kind of matter become quite subordinate and supplementary to the more accurate and delicate determination of chemical means.

26. (*d*) *The Thermometer.*—We have already noticed that the sense of feeling, and, indeed, all the senses, are singularly deficient in the direction of the quantitative determination of phenomena, such as either actual or relative temperature. The thermometer in its

various forms enables this to be done with the greatest ease. The principle upon which this instrument is constructed varies with the nature of the researches to which it is to be applied; but in all its more perfect forms which usually depend upon unequal expansion, or more delicate still when constructed to reveal thermo-electric currents, it enables us to determine differences in temperature which are far beyond the range of the sense of feeling or touch, even to detect in the slightest degree. No instrument has rendered more signal and fundamental service to physical science, and it is hardly too much to say that without it physical research would be absolutely impossible, so far as quantitative relations are concerned.

Inequalities on the surface of substances, such as a mirror or speculum, which cannot be detected by the most delicate touch, can easily be seen by the employment of instruments which use a ray of light to reveal the variation; and in this and many other ways the range of the natural sense is supplemented and extended.

27. *Instruments of Precision.*—Every department of physical science has now its appropriate instruments which aid the senses in observing the phenomena and in recording the numerical results, and many of these instruments are now carried to such perfection that they become self-registering, and thus record the results of the changes which they indicate without the aid of an observer at all. The description and use of these instruments are a necessary part of every course of instruction which is intended to impart a knowledge of the various sciences. The marked advances which have been made in mechanical science have enabled machines of great precision to be used in the construction of these instruments, and have introduced a degree of accuracy into their various parts which has enabled observations to be made, which a few years ago were quite impossible; and this process will no doubt be much extended in future years with ever increasing benefit. It is, however, necessary to point out that even these exact instruments have their

sources of error, quite independent of the errors due to the observer.

The liability to flexure in the parts arising from the elasticity of the materials out of which the instruments are constructed, the alterations which they undergo in consequence of unequal expansion from variation in temperature, as well as the necessary errors which arise from defective workmanship or improper adjustment, require to be specially determined before accurate observation can be made. This determination of instrumental error, indeed, often forms a by no means pleasing part of the work of every original investigator, and occupies a large share of his time and attention. Even here an observer's troubles do not end, for it is now definitely established that we cannot obtain any perfectly rigid and steady stand upon which to support our instruments, as the whole solid crust of the earth is subject to continual tremor and disturbance arising from various causes, and which much interfere with the determination of minute changes in position or motion.

28. *Mental Analysis.*—When all our observations have been completed, with the best instruments at our command to aid the senses, and with every care and attention bestowed upon the observations, so as to free them from both personal and instrumental errors, we are still only at the threshold of the real scientific work. We have obtained the materials, but the structure is yet to be reared, and this cannot be accomplished without mental analysis of the facts which these materials reveal. This may be said to consist in the classification of the observations, and in the deductions and inductions which are made from them, so as to arrive at more general truths, and, ultimately, at the reasons or causes for the phenomena. The distinction between these two methods of reasoning is important. *Induction* is an ascent from the particular to the general, or from effects to causes. *Deduction* is a descent from the general to the particular, or from causes to effects.

By induction from a sufficient number of particular facts we infer a general law; by deduction we apply this general law to the explanation of new facts. The province of induction is to discover the law which binds together a given number of facts; the province of deduction is to find all the facts illustrating the given law. In the first we have the facts given, and seek to find the law; in the second we have the law given, and seek to find the facts. In the same way by induction we discover the cause of certain phenomena; while by deduction we seek to discover all the phenomena of which it is the cause. Induction finds the force which produces certain effects; and deduction seeks all the effects which the given force produces. We are thus able to group our phenomena into still larger and larger classes, which present also a similarity in kind, and reasoning from these we reach the highest degree of generality of which science is capable, and are enabled to determine what are the axioms or fundamental truths in regard to the relations which subsist between the various phenomena.

The Combined Method is the method of science which may either rise from the particular to the general, or, by the reverse process, descend from the general to the particular. Induction may be said to be the method of investigation which seeks to determine the causes which lie underneath the phenomena, and which we term laws; just as deduction is the process by which the law inductively discovered is traced in new instances. In the inductive process we have first the facts and then the law; while in the deductive process we have first the law and then the facts which illustrate the law. Each needs the other, and both rest upon this principle of causality. All determination of the relationship of cause and effect, even in particular instances, arises from the employment of the combined method, being founded upon the mental certainty that every effect must have a sufficient cause; and consisting inductively in having the causes of the effects, and deductively in having the effects

of the causes. Our knowledge, for example, of the reaction of matter upon matter, in direct proportion to its weight and inversely as the square of the distance, is a strict induction from the whole of the facts and phenomena which the study of matter has revealed; but the assumption of the universality of the law of gravitation is the result of a deductive process resting upon the conviction that the relationship revealed by induction, arrived at from such wide experience, must hold good beyond the bounds of our possible experimental determination, even although that may extend to the farthest limit of the visible universe. Thus by induction we reach the law, but by deduction we infer its universality.

Thus the mind rises, step by step, to a higher and grander conception of the wonders which are revealed by the endless diversity in nature, and learns to see beneath the surface of all this diversity, an equally astonishing unity continually manifested. The fixed order and continuity which everywhere obtains, and the universal reign of law which, while hidden beneath the surface of material things, is ever presented to the mind, cannot but suggest that, beneath the thin veil which hides the unseen energies of the universe, there lies an all-pervading and omnipotent cause, the nature of which lies beyond the province of physical science to determine.

CHAPTER III.

STATICAL PHYSICS, INCLUDING THE GENERAL PROPERTIES OF MATTER.

29. *The General Properties of Matter* may be regarded as those distinctive peculiarities which matter, as such, always displays, and upon the perception of which our knowledge of its objective reality depends. These general properties of matter are divisible into two kinds, the one of which we may term *essential*, and the other *specific*. The essential properties are those without which we could not conceive matter to exist at all, and in whatever condition it might be found; whereas, the specific properties are those which depend upon the accidental state in which the matter exists at the time of the observation. Essential properties are therefore necessary attributes of matter; while specific properties depend on the peculiar state of atomic or molecular aggregation, and are subject to alteration along with the changing condition which matter undergoes when operated upon by force.

30. *The Essential Properties of Matter* may be regarded as three—(1) Ponderability or Weight; (2) Extension or Space Occupation; (3) Impenetrability. These properties of matter are true in regard to every kind of matter, whether it exists in the solid, liquid, or gaseous condition, and apply equally to the atoms which are the ultimate basis of matter, and to the molecules which are formed out of aggregations of these atoms.

31. (1) *Ponderability or Weight* is simply the word which we employ to signify that all matter possesses being, or mass, or quantity, by virtue of which it differs from nothing, or non-being, and it is quite impossible to present to the mind any idea or conception of matter which does not possess this property. The weight may be immeasurably small—so small that it may be quite im-

possible to determine its quantity by any instrumental or other means at our command—but the idea of a real weight, which enables matter to act upon other matter in its vicinity, and to be re-acted upon in like manner, can never be absent if we are to think about matter at all. We can no more banish this idea from our minds, when we think of matter in any form, than we can our fundamental ideas of space and time. Absolutely the mass always remains the same, because it is the real quantity of matter which forms the physical universe, and its increase or diminution, which is the creation of new matter or the annihilation of old, is inconceivable. The whole of physical science is indeed founded upon this doctrine of the conservation of matter, as revealed by its weight, because, if we could conceive for a moment that in any of the transformations which matter undergoes, when acted upon by force, any portion of it disappeared, or any matter was introduced into the quantity operated upon which was not originally present, we could place no reliance upon any quantitative experiments whatsoever; and such a science as Chemistry, which especially considers the quantitative relations of the various elements when in combination, would cease to exist. So far as any given quantity of matter is concerned, its absolute weight will remain the same, whenever and wherever it is considered in regard to the same quantity of matter either of its own or any other kind, and we measure this weight numerically by the intensity of the resultant of the earth's attraction upon the molecules of the body, or its gravitating force, which is always proportionate to its quantity, so that if we have double the quantity of matter we have double the gravitating power, or half the quantity of matter, half the gravitating power. Measured by this standard, however, the numerical absolute weight of a body does not remain constant in all parts of the universe, or, indeed, of the earth's surface, because, being the result of mutual attraction, it varies as the square of

the distance which intervenes between the two gravitating bodies. The farther, therefore, we remove a body from the surface of the earth, the lighter will it become, because the mutual attraction, upon which the measure of our absolute weight depends, is continually becoming less and less. This weight will also vary if we alter the standard mass of matter, against which a given quantity is weighed. Thus, while the mass of a given body might remain the same, it would weigh more upon the surface of the planet Jupiter than upon the earth, and be heavier still if transported to the surface of the sun. The pound weight is, indeed, rather heavier in Glasgow than in London, because the attraction of the earth acts as if it were concentrated in the centre of the sphere; and the form of the earth, which is an oblate spheroid, necessitates all places being nearer the centre of the earth as we proceed farther from the equator towards the poles.

Besides absolute weight, there is also *relative* weight, and, as we have already seen, this is quite independent of the conditions in which the matter is placed upon the surface of the earth, or of those of any other body in the universe, or of the distance at which it may be placed from the gravitating centre. This relative weight is that which we determine by means of the balance, and is nothing more than the ratio which the absolute weight bears to that of any other mass of matter which may be arbitrarily chosen as a standard of comparison. Thus, two pound weights which balance each other, will do the same either in London or Glasgow, or any part of the earth, or, indeed, of the universe, although their absolute weights, as determined by the power which they possess to compress or extend a spring, will vary in every fresh position in which they may be placed.

There is yet another kind of weight which we term *specific* weight, or specific gravity. This weight is really the relation which subsists between the mass or actual absolute weight of a body, and the volume or space

which the body occupies. In practice it is the relative weight of a given quantity of matter which occupies a given space, when compared with an arbitrary standard volume of matter which is selected as unity. Thus, all specific weights of solids are measured against the same volume of water, whose weight, at a given temperature, is taken as the standard; and all gases are weighed against a similar volume of hydrogen gas, whose weight is taken as unity. Thus we say the specific gravity or weight of the earth is five and a half, because it weighs five and a half times as much as a sphere of water of the same size or dimensions would do. This relation of mass or weight of matter to the volume which it occupies is also called *density*. Thus, if we cause a given volume of matter to be compressed until it occupies half the volume or space which it formerly did, we say its density is doubled, and so on in proportion to the volume which it is made to occupy when compared with its original volume. When measured by the same standards of volume and weight, the product of the volume multiplied into weight is always a constant quantity; and hence, when the weight of two or more bodies is the same, their densities are inversely proportional to their volumes. For the same reason, when the density of any two or more bodies is the same, their weights are directly proportional to their volumes; and when the volumes of any two or more bodies is the same, their weights are directly proportional to their densities.

32. (2) *Extension or Space Occupation.*—This property of matter simply means that all bodies or matter must possess magnitude. They must have a size of some kind, and must, therefore, take up or occupy a certain portion of space. This space may be so small that no means at our command may enable us to determine it; but if matter exists and is present in any confined space which we may select and which is measurable, the matter present must take up some room in that space, and thus lessen the vacuum within it which would exist if no

matter were present. All matter is extended in three directions, which we term length, breadth, and thickness, and we cannot think of matter without these three extensions being present in our minds. The relative proportions of these dimensions determine what we call the form or shape of matter. When these proportions bear certain relations to each other, we give the forms certain definite names. Thus, when they are the same in all directions, we term the body a sphere; when they are bounded by flat surfaces, which are all equal and six in number, we term the matter a cube, and so on for all the geometrical figures. In measuring the dimensions of bodies, we always employ the same units of measurement that we use in the measurement of linear distances, but suppose this measure to be extended in three directions. Thus, if we use the linear inch, our unit for space measurement occupied by bodies is a space which is one inch long, one inch wide, and one inch deep: and this we call a cubic inch. In the same way, taking the linear measures of a foot or a yard, we speak of a cubic foot or a cubic yard. This peculiar property of matter characterises it in whatever condition it may exist, because however great may be the attenuation or smallness of the size into which the matter may be divided, it can never be made to occupy no space any more than to have no weight.

33. (3) *Impenetrability.*—By this term, in the sense in which it is used here, we do not mean that matter can exist so hard that it cannot be penetrated by another body, such as a cannon-shot entering an iron target; but that since all matter, in whatever condition it exists, occupies space, so no two masses of matter or two bodies can occupy the same space at the same time. When a cannon-shot is driven by the velocity with which it is moving into an armour-plate or target, it simply forces aside the molecules of the iron which compose the target, and takes or occupies the space which they did; but the ball and the molecules of the target are never in the same

space at the same time, and the one must be removed and caused to occupy another portion of space before the other can enter. The law which holds good for solid bodies is equally true for both liquids and gases, although, especially in the latter case, it is not quite so easy to realise. A ship's hull simply displaces so much of the water in which it floats, and although the ship passes through the water, it can only do so by continually forcing aside the molecules of the fluid in front, while others fall into the rear of the vessel as it passes along; in no sense can the hull and the water be said to occupy the same space at the same time. In gases we have the same property, because if we try to make any two gases occupy the same space, we shall find it quite as impossible as to make two solids do so. The principle upon which the diving-bell is constructed depends upon the fact that when a vessel is filled with air, which is a gas, water, which is a fluid, cannot occupy the same space at the same time. We shall afterwards see that although no two masses of matter can occupy the same space at the same time, yet from the probable nature of the constitution of matter there is always such a distance between the molecules of matter, in proportion to the actual diameters of the molecules, that they never really touch each other; and that there is always, therefore, room in the spaces between the molecules for other molecules, which are in a different condition of aggregation, to exist without interference with each other. Thus, many solids, which seem to the ordinary senses to fill all the space which they occupy, can absorb and condense within them a large quantity of certain liquids or gases. In the same way, many liquids can absorb large quantities of gases, and many gases or vapours interpenetrate each other. In no sense, however, do they occupy the same space at the same time, since each separate molecule of matter occupies entirely its own space, and the others which are along with it occupy separate spaces side by side.

34. *The Specific Properties of Matter*, as we have

already seen, are those which depend upon the peculiar condition in which the matter may exist at the time when our observations are being made, and are all of them such that we can easily conceive of matter as existing independently of them.

We may consider these properties as seven in number: viz.: — (1) Divisibility; (2) Porosity; (3) Compressibility; (4) Elasticity; (5) Cohesion; (6) Adhesion; and (7) Inertia.

35. (1) *Divisibility* is that property of matter upon which our power to divide it into smaller portions depends. This division of matter can be carried on to an extent which far exceeds the power of the senses to determine. Thus, a single grain of gold can be mechanically beaten out until it will cover fifty-seven square inches, although the original bulk was not more than the $\frac{1}{5,000}$th part of a cubic inch; and this film is so thin that 282,000 of them, placed like the leaves of a book one upon the other, will only occupy the thickness of one inch. By chemical means, this division can be carried to a far greater extent, and one single grain of gold made to cover a surface of about 9,600 square inches, while the thickness of the film is reduced to the $\frac{1}{5,000,000}$th of an inch. The thickness of a soap-bubble, which consists of a thin film of soap and water, is only about the $\frac{1}{156,000}$th of an inch at the time it bursts; and when the water is raised into the form of steam or vapour, it is most probable that each separate molecule of water-vapour is far more attenuated than the thickness of this film represents. There is, however, reason to believe that there is a point beyond which the division of matter cannot be any longer continued, and we then reach the ultimate atom or smallest portion of matter which can exist, and which cannot be divided any farther because it has no parts. From a variety of physical experiments, it seems probable that the size of the ultimate atom does not exceed the $\frac{1}{500,000,000}$th (one five hundred millionth) of an inch in diameter. Professor Thompson has calculated that every

cubic inch of a gas at the ordinary temperature and pressure of the air, contains one hundred thousand millions of billions of molecules—a quantity which exceeds all the powers of the human mind to conceive. Although in these calculations there are necessarily wide limits of error, they nevertheless point to the fact, that all the ordinary matter which appeals to our senses is really an aggregation of much smaller masses; and the results of chemical investigation render it all but absolutely certain that the division of matter cannot be indefinitely extended, but that we ultimately reach a point where division is no longer possible, and that the various elementary bodies are composed of atoms or ultimate particles of matter which have each a definite size and weight, and out of which the molecules, or secondary particles of matter, are built up.

36. (2) *Porosity*, or the existence of interstices or spaces between the molecules which build up the mass of matter, follows as a consequence of what we have already stated, that the molecules do not touch each other. These physical pores are in general so small that they cannot be detected by the unaided senses any more than the molecules themselves, but can be easily revealed by the aid of various experiments. Water enclosed in a gold or other metal globe and subjected to pressure, will force itself through the pores of the metal, and stand like drops of dew upon the surface; and almost any ordinary solid, when immersed in water, will reveal the existence of pores, by the escape of the air which is enclosed within them, and which rises to the surface in bubbles; or by the fact that it can absorb water within the pores, and, consequently, increases in weight after immersion. In many bodies the pores are so large that they can be detected even by the naked eye, as in a sponge, or, at any rate, under the microscope, as when we examine the cellular structure of any organic substance. These larger pores may be termed sensible pores, to distinguish them from the physical pores which arise from the molecular structure.

37. (3) *Compressibility.*—This property of matter is a natural result of the last, because since the structure of matter is such that there are spaces or pores existing within the general bounding limits of the substance, it is capable of being squeezed into smaller space, and thus made to assume a greater density when subjected to pressure. Different materials differ very much in regard to the degree of compressibility which they exhibit, and it will be quite obvious that, as a rule, solids are much less compressible than gases, which can be made to change their volume with very slight degrees of pressure. Liquids, like solids, offer very great resistance to compression, and, indeed, upon this fact depends the construction of the hydraulic press, where the force is transmitted from the small cylinder to the large one through the medium of water, and which water, because it can only be very slightly compressed even when subjected to enormous pressure, raises the ram rather than change its volume. Those substances which are the most porous are, as a rule, the most compressible; and in the case of solids, when a sufficient pressure is exerted, the solid structure ceases to compress any farther, and becomes disintegrated, or broken up, or else offers such a resistance that it changes its form permanently in those directions where it is free to expand. In the case of gases, a sufficient pressure ultimately causes them to assume the liquid form, and they then display the same resistance to compression as liquids.

38. (4) *Elasticity.*—When any substance is subjected to compression by the action of pressure, it usually returns again to its original form when the pressure is removed, except that all solid substances acquire, when continually subjected to compression, a small permanent set or tendency not to again exactly attain the same original volume. Thus, if we stretch an india-rubber band or metallic spring, it will return again to its original shape when the tensile strain is removed, and this property we term elasticity. This property is characteristic of almost all

matter in a more or less degree, because it arises from the existence of attractive or repellent forces acting upon the molecules of which the body is composed, and, as we might naturally expect, it is exhibited in the highest degree in those substances, such as gases, which also possess the property of compressibility to the greatest extent. A gas when subjected to pressure which causes it to diminish in volume never acquires a permanent set, but always, when the pressure is removed, returns to its original volume. This property is well illustrated in the principle of the air-gun, where the liberated air expels the ball from the barrel with almost explosive violence, by virtue of the elasticity; or in the enormous power which is exhibited in the elastic force of steam which is compressed into our high-pressure boilers, and which can do work against the most tremendous resistance. The elasticity of liquids is comparatively small when compared with that of either solids or gases. When an india-rubber ball is permitted to fall from any height on to a hard substance, the rebound which succeeds the impact arises from the elasticity of the body, the molecules of which are forced inward by the force of the blow, and drive the ball upwards again by their elastic force, which enables them to regain their former shape.

39. (5) *Cohesion* is that property of matter by means of which the molecules, or particles of matter, unite, and remain in contact, so as to form one mass. It is one of the molecular forces which only acts through a small distance, and this distinguishes it from the force of gravity, by means of which two masses of matter attract each other. It is distinguished from chemical attraction, which unites the atoms of different kinds of matter, so as to form new substances, by the fact that it unites the molecules of the same kind of matter alone, and in the same way it differs from adhesion, which unites the molecules of different kinds of matter. We measure the force of cohesion by the power or force which it is necessary to exert in order to tear asunder the molecules

of any body, or force them apart by crushing or shearing. This force is very different in different substances, and while it is always considerable in solids, it is very feeble in liquids, and entirely absent in gases. These three different conditions of matter, indeed, appear to be the result of the overcoming or balancing of this force by the action of heat. In all solid substances the swing of the molecules is so small that it does not overcome their mutual attractions, and they are not, therefore, free to move away from each other. In liquids the motion of the molecules, which constitutes heat, has overcome their mutual attractions, so that they are free to move over each other, but not, except at the free surface of the liquid, able to tear themselves entirely asunder. In gases the force of cohesion, or the mutual attraction of the molecules, has been entirely overcome, and, therefore, ceases to exist as a binding force, and in consequence there is not only not any tendency to remain together, but a force which drives them asunder, so that there is no superior limit to the expansion of a gas which tends to diffuse itself continually through a larger space, as the pressure which restrains it is removed.

The property of cohesion receives different names from the various special characters which it imparts to matter. When the particles of a body are united by this force in a feeble manner, so that they can be easily caused to change their relative position, we term the body *soft*; and when the force is exerted strongly, so that they offer very great resistance to any change of position, we term it *hard*. If the character of the cohesion is such that when the force has been overcome the molecules readily fall away from each other, we term it *brittleness*. This character is eminently characteristic of almost all crystalline substances, because the molecules are arranged in the body in regular order, and do not interlock into each other, but form plane surfaces of contact, so that we can easily shiver them, as in the case of glass.

Malleability is the opposite property to brittleness, because in all malleable substances we can extend or draw them out under the action of force, and cause the molecules to change their relative positions without so entirely overcoming their cohesive attraction that they fall asunder. Many metals, such as gold, or platinum, or silver, exhibit this property in a marked degree, and can be, as we have already seen, beaten into thin plates or leaves of astonishing tenuity. They can also be drawn out into exceedingly fine wire, and this property we term *ductility*. The power with which a wire or other similar substance, such as a hemp rope or a silk fibre, resists any endeavour to tear it asunder, and which depends upon the cohesive attraction of its molecules, is called *tenacity*.

40. (6) *Adhesion*.—This term is used to signify the power which two substances, either of the same or different kinds, possess to unite or stick together when brought into contact and subjected to pressure. Thus, two plane metal surfaces, or, indeed, perfectly true surfaces of any kind of matter, when presented together unite with great ease, and require considerable pressure to tear them asunder. This is in many cases partly due to a partial vacuum being formed between them, and the pressure of the air is then exerted to keep them together; but apart from this they will unite, and if the surfaces are perfectly clean from foreign or greasy matter, they become, after a time, almost like one body. The use of gum or other mucilaginous matter which interlocks into the molecular surfaces, or excludes the air, and then sets hard, is well known as enormously increasing this power. The adhesion of solids and liquids is seen by the fact that when the solids are immersed in liquids, they come out wet, or have a thin liquid film adhering to the surface of the solid; and if we try to pour out a liquid out of a solid vessel, the power of adhesion causes drops to cling to the side of the vessel, and renders it difficult to discharge them without spilling, unless a suitable spout or orifice is

made, which offers the least surface for adhesion. The adhesion of gases to the surfaces of solids, is well seen in the bubbles of air which always are attached to solid bodies when immersed in liquids, and if the solid be, say a lump of sugar, which will melt in the liquid, the air can be seen clinging to the surface until it is entirely melted.

41. (7) *Inertia.*—This is a purely negative quality of matter, and may be defined as the power which all bodies possess of remaining in the same condition in which they are, whether at rest or in motion, unless they are acted upon by external conditions. Thus, a body at rest will remain in that condition for ever, unless operated upon by some external cause which can give it motion, and when once in motion it will continue in motion for ever, unless some opposing force act upon it, and thus reduce it to a state of rest again.

Under ordinary circumstances bodies, when set in motion, do not continue in this condition, but come to rest again, because they are operated upon by such powerful agents as friction or resistance, whether this results from coming in contact with another body, or the slower contact with the air or other medium in which the body may be moving.

A body moving on a smooth surface continues in motion much longer than when moving on a rough surface, where the friction is greater; and if we remove the air from the case in which a pendulum is vibrating, or a top spinning, they continue in motion for a longer time, because the friction of the air upon the moving body is no longer in operation. In a railway collision, most of the danger to the passengers and rolling stock arises from the inertia of their bodies and of the material of which the train is composed. When the train is suddenly arrested, the passengers continue to move, and are thus thrown violently against each other and the sides of the carriages, while the carriages themselves are broken by the endeavour to continue the motion of their parts, when the motion of the mass is stopped. When the motion of a

mass of matter is arrested suddenly, and the inertia does not tear asunder the molecules of which it is composed, the motion of the mass is transferred to the molecules, and the mass becomes heated as a consequence.

CHAPTER IV.

DYNAMICAL PHYSICS, INCLUDING THE NATURE OF FORCE AND THE LAWS OF MOTION.

42. We have already seen in the last chapter that all matter possesses the property of inertia, by which we mean that whether at rest or in motion, it cannot alter its state without the operation of some external cause. Every cause which is capable of acting upon a body, so as to change its state from a condition of rest to that of motion, or of changing the rate of motion, is called a *force*.

43. *Force* may be derived from many sources in the physical universe; and such forces are named from the phenomena which they exhibit when acting upon matter. Thus we speak of *mechanical force* when the motion communicated to any body is derived from the motion of any other mass of matter, such as the blow of a hammer driving in a nail or breaking a stone. *Muscular*, or *vital force*, may be the source from whence the hammer derives its motion. We term the force *molecular* when it is derived from the motion or constrained condition of the molecules of a body, such as the compression or elasticity of a spring or bent bow, or the expansion of a gas or vapour, such as steam, which may give motion to an arrow, or momentum to a fly-wheel in an engine or train.

When the source of force is atomic combination, such

as the explosion of dynamite or gas, we call it *chemical;* and when the source arises from a polar or mutually attractive and repulsive condition in matter, we term it *electric* or *magnetic force. Thermic,* or *heat force,* is spoken of when the source of the motion, or resistance arises from the action of absorbed heat, such as the expansion of water into steam when it is boiled by the action of fire; and *radiant force* when the force arises from the action of radiant heat, light, or actinism. A general term for all these forces is *energy,* of which they are all special forms, and which energy we may define as the power to do work against resistance.

44. *Kinds of Force.*—When viewed in relation to dynamical considerations, we may regard forces not in regard to the sources from whence they are derived, but to the nature of the effect which they produce upon matter. In this sense we may distinguish two different kinds of force, *active* or *accelerating* force, which tends to augment or increase the motion of a body; and *passive* or *retarding* force, which tends to bring the body to rest, but which is, after all, only a force producing an effect in an opposite direction. Forces may also be regarded in relation to the time of their duration when acting upon matter. Thus, when they are always in active operation, such as in the attraction of the earth, or the resistance of the atmosphere, or the friction in a train of mechanism, we term the force *continuous.* When they operate at intervals, whether the time be short or long, such as the blow of a hammer, or the expansion of steam in a cylinder, which is admitted by the alternate action of a valve, we term the force *intermittent.*

Instantaneous forces are those which act for an indefinitely short period only, such as an explosion of gunpowder. When one or more forces are operating upon a body, and it still remains in a state of rest, we speak of the condition of the forces as one of *equilibrium,* because they neutralise each other's effects.

45. *Estimation of Force.*—The difference between the

effects which any two or more forces are capable of producing we term the ratio of their *intensity*, and we measure this intensity by the comparison between the forces whose effect we desire to measure, and some other force whose effect or intensity is taken as a standard. This effect is estimated in this country by the work which the force will accomplish when entirely employed in raising a weight against the force of gravity, which is a constant quantity. The *unit* of *work* is the pound weight raised one foot high, and we therefore estimate the intensity of a force by the number of pounds weight which it will raise against the force of gravity when operating for one minute of time.

From what has been already said in regard to the nature of the action of the various kinds of forces, it will be easily seen that the time during which they act is a very necessary element in the measurement of their intensities when comparison is to be made, because in the case of the instantaneous forces they can do an immense amount of work during the short time in which they are in operation, while the continuous forces may be able to accomplish the same work, but will occupy a longer period in performing it. For example, a cannon-shot can be projected upwards by the explosion of gunpowder in an instant of time, but the same weight could be raised to the same height by a much less energetic force acting over a longer period of time.

In the same way, the height to which the weight is raised is equally important, and it is found that a constant relation always subsists between the weight raised and the height to which it can be raised in a given time. This relationship is such that with any given expenditure of force, if we multiply the weight in pounds by the height to which it can be raised, or the space through which it is moved in feet, the product is always a constant quantity. Thus the same force which will raise 100 lbs. weight 10 feet high will also raise 10 lbs. weight 100 feet high, because $100 \times 10 = 1{,}000$, and

$10 \times 100 = 1{,}000$. This constant relation has been termed the principle of *virtual velocities*, and holds good for all forces when performing work, as well as for all mechanical arrangements which can be possibly devised for utilising the action of forces in the doing of work.

46. *Motion.*—Whenever force acts upon matter, it always produces, or tends to produce, motion, because in cases where equal resistance to the force is encountered, equilibrium is established, and the body remains at rest. Whenever motion takes place, however, it may be of two kinds: either *rectilinear*, if the motion takes place in a straight line, or *curvilinear*, if in a curved or non-rectilinear path; and in each of these cases the motion may be either *uniform* or *variable.* Uniform motion is that in which the body moves over equal spaces in equal times, like the hands of a clock; and variable motion when the rate of motion is continually changing, the same as in the swinging of the pendulum of the clock, which is continually changing from rest to motion, and continually altering its rate of speed between the two conditions. When any moving body is continually altering the speed with which it is moving, or the space over which it is passing in a given time, we term the rate or measure of increase with which this is accomplished the *acceleration;* or if the motion be decreased, the *retardation* of the motion.

When a body is undergoing change of motion, the original motion, or space moved over in a given time before the acceleration began, is called the *initial* velocity; and the speed at which it moves, or the space moved over in a given time when the acceleration is completed, is termed the *final* velocity. The *unit of velocity* is the space in feet moved over by the body in one second of time; and this quantity multiplied into the mass or weight in pounds of any moving body is called its *momentum.* The *unit of momentum* is one pound of matter, moving with a velocity of one foot per second; and when measuring the effect of any force we employ as

the *unit of force* that force which, acting for one second of time, produces in the unit of mass, or one pound weight, a velocity of one foot per second. In each of these cases we may put an ounce or a ton in place of a pound, or an inch or a mile in place of a foot, and their relative value will not be altered.

47. *Laws of Motion.*—The relation existing between force and motion may be expressed by what are termed the Laws of Motion, and which are three in number.

(I.) First Law of Motion.—*Every body continues in a state of rest or of uniform motion in a straight line until it is compelled by some force or forces to change that condition.*

This law is only a more complete definition of the property of inertia (41), about which we have already written; but it also involves considerably more, because it not only asserts that the action of force is necessary to produce motion in a body at rest, and rest in a body in motion, but also that force is also necessary to change, in any body in motion, not only the direction of the motion, but also its rate of motion, or acceleration; so that when we have a body moving in a straight line, it requires the action of a force operating upon it from without to change the direction of the motion. We have an instance of this in the attractive power of the sun, which bends the path of the earth's motion, which would otherwise be rectilinear, into a curved orbit, so that it revolves round it. A falling body would also drop towards the earth with a uniform motion, if it were not that the action of gravitation is continuously operating during the whole period of the fall, and is thus continually altering the speed with which it moves, so that the final velocity is proportional to the square of the time through which the pull of the earth has been acting. Here we have the force acting in the direction of the motion of the body, and producing acceleration or alteration of rate; but if the body be moving along the surface of the earth, the same as a cannon-shot discharged horizontally, this

force, instead of ceasing to act, produces change of direction, and the otherwise straight path of the shot is changed into a curve, which finally touches the surface of the earth.

48. (II.) SECOND LAW OF MOTION.—*When a body is in motion under the influence of any number of forces, each force produces the same effect as it would if the other forces were not acting, and the change of motion or direction is proportional to the moving force, and takes place in the direction of the straight line in which the force or resultant of forces acts.*

This law asserts that there is no such thing as the annihilation of the action of any force upon matter, but that all forces produce their effects in direct proportion to their intensities; and when two or more forces acting upon any body produce equilibrium, or a state of rest in a body, it is not because the forces themselves are balanced, but their effects.

To estimate the effect which any force acting upon a body will produce, it is necessary that we should know the point or position of the body on which it acts, and which is called the *point of application*—the *direction* in which it acts, or the right line which it tends to cause the point of application to describe—and its *intensity*, which we have already seen is measured by comparison with the effect produced by some other force which is taken as the standard. To estimate the effect which two forces will have when acting concurrently upon a point, we have only to consider the question as to the effect which each of them would produce in a certain time by giving to the point a certain velocity in a certain direction, and then consider their joint effect by finding the common resultant in direction and intensity. When two or more parallel forces are applied to the same point, their resultant is equal to the difference between the sum of those which act in one direction and the sum of those which act in the opposite direction, and this resultant acts on the side in which there is the greater sum. The

resultant of two concurrent forces is represented in direction as well as intensity by the diagonal of a parallelogram, whose sides represent the components in intensity and direction. By taking the forces acting upon a body thus separately, and compounding their results, we can thus estimate the effects produced by any number of forces in intensity and direction, and thus determine the final result produced.

A good illustration of this compound action of forces upon a body may be seen in a boat which is being rowed across a river. If the head of the boat is kept across the stream, it will be urged forward by the action of the rowers in the direction of its length, but at the same time it will be carried sideways down the stream by the current of the running water, and will finally reach the other side of the river, not at a point directly opposite to where it started, but at a point considerably lower down, and which will vary with the strength of the current. The centre point of the boat will have pursued the diagonal path of a parallelogram, of which one side will be represented by the breadth of the river, and the other by the distance down the river from the point at which it started to that point at which it reaches the other side. The passage, however, will have been made in exactly the same time as if the river had been a pond without motion, because the forward motion of the boat by the action of the rowers is in no way interfered with by the motion of the stream—the effect produced by each on the motion of the boat in no way interferes with the other.

When a body in motion comes in contact with a body at rest of any size such that motion can be imparted to it, something like the following results take place :—Either the body at rest is dashed forward, and the motion of the striking body is changed in direction, or continues in the same direction with diminished force, or is entirely stopped; or else the two bodies after the collision will move in opposite directions, arising from what we term in ordinary language the rebound. If the striking body

is small in mass when compared with the body struck, the effect will seem to be produced entirely upon the body which is in motion, and it will be driven away from the larger mass just as if it had not produced any effect upon it. The effect produced is, however, exactly the same whether it sets the body in motion or not; and we term the effect of the body in motion upon the body at rest the *action*, and the effect produced by the body at rest upon the body in motion the *re-action*. The relation between these two is defined in the third law of motion.

49. (III.) Third Law of Motion.—*To every action there is always an equal and contrary re-action*—or, in other words, the mutual actions of any two bodies are always equal, and oppositely directed in the same straight line. There are two different senses in which this law may be interpreted which are entirely different, and yet in each of them it holds equally true. The first case is that of simple pressures, or re-actions, in which the truth of the law is almost self-evident. If we press our hand against a wall, the wall presses back against our hand with an equal pressure. If we take two spiral springs of equal strength and press them together, both are equally compressed, showing that the action and re-action are equal; and this holds good whether we compress them both or only one of them against the other. If we connect the two bodies by a rod or a cord, so that we can have the pressure in extension as well as compression, we find it equally true; and, indeed, it is not necessary to have any connection, because the law holds good for fluid or gaseous pressures, and even for such attractions as that of magnetism or gravitation. The attraction of the magnet for the keeper is exactly the same as that of the keeper for the magnet, and the attraction of a stone for the earth the same as of the earth for a stone. It will, however, be readily seen that in all these cases the two opposing forces which are represented by the action and re-action are acting in the same straight line, but that there are *numerous* cases, especially when we come to consider

bodies in motion, in which both the action and the re-action are the result of combinations of forces which produce a series of results in which the motions of the bodies are not in the same straight line. We have already seen that the effect produced upon a body by two concurrent forces which are not acting in the same straight line is equal both in magnitude and direction to that produced by the force which would be represented by the diagonal of a parallelogram whose sides represented the original forces in magnitude and direction; and in the same way, the action of a force in a given direction upon a body which is not moving in the same straight line may be resolved into two forces which are acting in different directions, but which bear the same relation to it as the sides of a parallelogram of which it forms the diagonal. Thus, when the wind blows upon the sails of a ship which is not sailing in the direction in which the wind is blowing, the velocity of the ship depends not upon the whole velocity of the wind at the point at which it is applied, but upon the component of that velocity in the direction in which the ship is moving. Viewed in this light, therefore, we have not to consider the force alone when we come to estimate the effects of action and re-action, but the product of the force into its velocity, and in the case of the re-action, the resolved portion of the force into its velocity. The second case in which this law holds good may therefore be stated as follows:—If the action of an agent be measured by the product of the force into its velocity, and the re-action of the resistance be measured by the velocities of its several parts multiplied into their several forces, whether these arise from friction, cohesion, weight, or acceleration, action and re-action in all combinations of machines will be equal and opposite.

Had Newton, who first enunciated this second definition of the law of action and re-action, known what is now discovered in regard to the nature of heat and light and magnetism, so that he could have correctly estimated the amount of work done by the expenditure of a given

amount of force, as well as the rate at which the work could be done under the different conditions presented by the various kinds of machines, he would undoubtedly have arrived at a complete demonstration of the modern doctrine of the conservation of energy, which asserts that the sum total of force, like matter, can neither be increased nor diminished.

Part II.

UNIVERSAL GRAVITATION, INCLUDING A SKETCH OF THE PRESENT CONDITION OF ASTRONOMICAL KNOWLEDGE.

CHAPTER I.

TERRESTRIAL GRAVITY.

50. *Gravity.*—The term gravity is used to denote that property of matter by means of which any two masses or molecules attract or tend to approach each other. This property, as we have already seen, is inherent in all matter, whether at rest or in motion. The action is mutual between all masses of matter (31), and varies directly as the mass of matter and the inverse square of the distance between the attracting bodies. Thus a double mass of matter exerts a double attraction, and a threefold mass a threefold attraction. When the attracting bodies are at twice the distance, they exert only one-fourth of the attraction which they formerly did, and if removed to eight times the former distance, only one-sixty-fourth of the power. In the same way, when two bodies approach each other their attraction is proportionally increased. If the distance is diminished by one-half, the attraction is increased four-fold, and if by nine-tenths, then the attraction is increased one hundred-fold. When the two masses of matter differ in size, the mutual attraction is directly proportional to the product of their masses. Thus, if one mass be represented by 4, and another by 6, their mutual attractions will be represented by 24. The force of gravity is

really the result of the mutual attraction of every molecule of matter which composes one mass upon every molecule which composes the other; but when the masses of matter are symmetrical, such as spheres, they act upon each other just in the same way as if their whole mass were concentrated in their centres.

51. *Terrestrial Gravity.*—In consequence of this law, the force of the attraction of the earth may be regarded as concentrated at its centre, and the mutual attraction of the earth and any body placed on its surface, varies directly as the mass of the body, and inversely as the square of the distance from the centre of the earth. In consequence of the shape of the earth not being a perfect sphere, but an oblate spheroid, which is like an orange, flatter at the poles than at the equator, the force of gravity varies with the latitude of the different places on the surface of the earth. The force of gravity is also modified by the centrifugal force which is generated by the rotation of the earth, and which force is in opposition to that of gravity, being greatest at the equator, and vanishing altogether at the poles. This centrifugal force is at the equator about $\frac{1}{289}$th part of that of gravity; and if, therefore, the velocity of the rotation of the earth were increased seventeen times, the force of gravity of any body at the equator would be entirely neutralised, and its sensible weight cease to exist.

52. *Direction of Gravity.*—In consequence of the attraction of two masses of matter acting as though the force were concentrated in their respective mass centres, the direction in which the force acts is in that of the straight line which joins their respective mass centres. However unsymmetrical any mass of matter may be, there is always a certain point within the mass, whatever way the body may be turned with regard to the earth, through which the resultant of the attracting forces between the molecules of the earth and of the body passes. This point is termed the *centre of gravity.* The action of gravitation upon any body, therefore, reduces itself to a single vertical

force applied at this centre of gravity, and directed to the centre of the earth; and whenever this resultant is neutralised by the action of the resistance of a fixed point, such as a support, or a suspending string, or other unyielding medium, equilibrium is established. With regard to the surface of the earth, therefore, the centre of gravity of all bodies tends to occupy the lowest possible position. Whenever the form or relation of a body, with regard to the attraction of the earth, is such that when the equilibrium is disturbed by the raising of the centre of gravity it tends to return to its former position, we speak of it as being in *stable equilibrium*. A pendulum is a good example of this stable condition. When the relation of the centre of gravity is such that when once disturbed it tends to depart farther and farther from its original position, we say the body is in *unstable equilibrium*. A rod of small diameter, such as a pencil placed vertically upon a table, is an illustration—any disturbance causes it to remove farther and farther from the vertical position until it falls flat upon the surface. When the position of the body makes no difference to its condition in regard to motion, such as a round ball, which will stand upon a flat surface, and remain in any position in which it may be placed, we term it in *neutral equilibrium*. Any suspended body upon the surface of the earth places itself in such a position, that when stable equilibrium is established, the line of the suspending string points in the direction of the centre of the earth. This line we term a *plumb-line*, and a *horizontal surface*, such as that assumed by the molecules of any liquid which are free to arrange themselves in equilibrium under the action of gravity, is always at right angles to this vertical line. It will be easily seen that in consequence of the earth being a sphere, no two plumb-lines are strictly parallel, but they may be considered as practically so, if the distances between them are only small. Mountain masses disturb the direction of the plumb-line, and in this way, by measuring the disturbance caused by a mountain in

Perthshire, the relation of the mass of the mountain to that of the whole globe was obtained.

53. *Measurement of Gravity.*—The attraction of gravitation is most conveniently measured by the amount of motion which it is capable of imparting to a body which is free to fall towards the surface of the earth in a given time. In a vacuum, all bodies receive an equal acceleration, under the action of gravity, in the same time, so that a feather and a ball of lead permitted to fall from the same position reach the ground at the same time. Under ordinary conditions, the resistance of the air retards the fall of the feather more than that of the lead ball. As already stated, the force of gravity varies to a small extent with the latitude of the place; and at the latitude of London the acceleration imparted to a falling body may be taken at about 32 feet 2 inches per second.

Another, and more exact, means of measuring the force of gravitation is by observing the oscillation of a pendulum—the time of the oscillation of any two pendulums of the same length, or of the same pendulum, being inversely proportional to the square root of the intensities of gravity at the places in which the observation is made. In the latitude of London a pendulum 39·139 inches in length exactly completes one vibration in one mean solar second, and we have therefore by this method, in addition to a measure of the intensity of gravity, an exact means of the measurement of time. In the same way we can calculate from the time of oscillation of any pendulum its exact length, because the time of vibration is proportional to the square root of its length; and we could thus at any time restore the exact length of the inch, or foot, or yard, if the standard were lost, by observing the time of oscillation of the pendulum.

The time of oscillation of the pendulum also enables us to determine with great exactness the precise figure of the earth, because since the action of the earth's mass upon the pendulum swinging outside its surface acts as if it were concentrated at the centre of the earth, and

thus affects the time of oscillation, we can determine by this means the distance of any point on the earth's surface from the centre of the earth, either relatively or absolutely. The time of oscillation of the same pendulum decreases as we ascend a mountain, and also as we descend a mine, because in the latter case, although we approach the centre of the earth, the action of the superincumbent shell of matter left behind retards the swing of the pendulum, and shows us that the attraction of gravitation, although it acts as if it were concentrated at the centre, really resides in each molecule of which the mass is composed.

CHAPTER II.

THE PLANETS AS GRAVITATING BODIES.

54. *Celestial Gravity.*—The earth not only exercises an attraction upon all bodies placed upon its surface, but also, strictly speaking, upon every other mass of matter in the physical universe, however distant the masses may be. The recognition of this great fact formed the starting-point from which Newton deduced the grand theory of universal gravitation. In order to accomplish the proof of this theory, Newton first determined how far a body would fall in one second of time when continuously accelerated by the force of gravitation upon the surface of the earth, and then computed how far it ought to fall in the same time when acted upon by the attraction of the earth at the distance of the moon, supposing the power of the earth's attraction to be decreased as the square of the distance increased. When this computation was first made, the distance of the moon from the earth was only very imperfectly determined, and as the force of gravity decreases

as the square of the distance, a very small error in the distance causes a great discrepancy between the distance through which the moon itself ought to fall towards the earth, or be bent out of a straight path, and the actually observed distance through which it did fall. This error between theory and observation, which amounted to about one-sixth of the entire distance through which the moon ought to be drawn out of a straight path, retarded the proof and acceptance of the law of gravitation, as applied to the heavenly bodies, for many years; and it was not until an entirely new determination of the diameter of the earth, obtained by the measurement of an arc of the meridian, enabled the distance of the moon to be accurately known, that, when the calculations founded upon the new distance were determined, it was discovered that the observed and calculated distance through which the moon ought to fall towards the earth in one second of time were in strict accord with each other. The earth's power of attraction was thus shown by absolute demonstration to extend out into space as far as the orbit of the moon, and to act, according to the same fixed law which regulates the descent of a stone to the earth, in deflecting the path of the moon from a rectilinear course, and thus converting the direction of its motion into an elliptical orbit, so that it maintains in every part of its revolution the most perfect equilibrium. From the earth and moon, as a system, it was easy to extend the calculations and observations to the planets and sun, and it was then found that the same law regulated their motions and relations, and is reasonably conjectured to extend far beyond the bounds of the solar system into the most distant regions of space.

55. *Solar System.*—The earth and moon, the latter of which revolves round the former, are only part of a much larger system of mutually gravitating bodies which revolve round a common centre, the sun, and which, by its enormous mass, far exceeding and outweighing all the other members of the system, exercises a preponderating

influence upon them, and bends their various paths in space into a curvilinear orbit round itself. The various bodies which compose the members of this system differ much in mass and density (31), and in the distances at which they are situated from the sun. They number altogether several hundreds, including the comets, which are known to belong to the system, and, from the increasing number of smaller planets which are continually being discovered, are probably much more numerous than at present determined.

The members of the solar system may be regarded as of four different kinds:—

1. The large planets, which are eight, or possibly nine, in number.
2. The smaller planets, or asteroids, which revolve round the sun between the orbits of Mars and Jupiter.
3. The comets and meteorites, which are now proved to be related to each other.
4. The satellites, or moons, which in varying number accompany many of the larger planets.

56. *The Large Planets.*—The large planets are placed in the following order with regard to the sun, the first being nearest, and having, therefore, the smallest orbit:—

1. Vulcan.—This planet is supposed by many astronomers not to exist, and it cannot be regarded as certain.
2. Mercury.
3. Venus.
4. Earth, accompanied by 1 satellite, or moon.
5. Mars „ „ 2 satellites, or moons.
6. Jupiter „ „ 4 „ „
7. Saturn „ „ 8 „ „
8. Uranus „ „ 4 „ „
9. Neptune „ „ 1 „ only known.

All these planets move round the sun in one direction—viz., from west to east, and they also move on their axis

or rotate, in the same direction. The moons also all revolve round the planets to which they are attached from west to east, with the exception of the four moons of Uranus, which move in the opposite direction; and it is also probable that the moon of Neptune may also be another exception.

All these planets also move or revolve round the sun very nearly in one plane—the plane which is marked out by the apparent motion of the sun in the heavens, as seen from the earth, and which is called the *plane of the ecliptic.* The orbit of Mercury has the greatest inclination, which is about 7°, and the whole of the planets, therefore, move, or appear to move, round the celestial vault in a narrow zone or belt, sometimes above and sometimes below the plane of the ecliptic. This zone is called the *Zodiac.*

57. *Distances of the Planets.*—The relative distances of the planets from the sun was known at a much earlier period than their actual distance. This relation seems to follow a curious law, which is known as Bode's law, from the German astronomer who discovered it. No reason has ever been assigned for this law, so that we do not know upon what cause it depends.

We may present the law in a simple form by writing the following series of figures :—

	0	3	6	12	24	48	96	192
Add	4	4	4	4	4	4	4	4
	4	7	10	16	28	52	100	196

If 10 be taken to represent the distance of the earth from the sun, these figures represent very nearly the relative distances of the other planets, as will be seen thus :—

	Actual Relative Distance.	According to Bode's Law.
Mercury	3·3	4
Venus	7·2	7
Earth	10·0	10
Mars	15·2	16
Jupiter	52·0	52
Saturn	95·3	100
Uranus	192·0	196

It will be seen that between the orbits of Mars and Jupiter one of these relative numbers, 28, is left out in the larger planets; and this omission, which seemed to indicate that there should be a planet in this space, led to the search for, and discovery of, the asteroids.

The relative distances being known, it is only required to determine accurately the distance of any one from the sun in miles, or any other unit, and all the others can be then easily calculated. This distance has been determined for the earth, and found to be about 91,430,000 miles, so that the actual distances of the planets and their periods of revolution round the sun are as follows:—

		Distance in Miles.		*Period of Revolution round the Sun.* *Days.*	*Hours.*	*Min.*
Vulcan (?)	...	17,372,000	...	19	17	0
Mercury	...	35,393,000	...	87	23	15
Venus	...	66,130,000	...	224	16	48
Earth	...	91,430,000	...	365	6	9
Mars	...	139,312,000	...	686	23	31
Jupiter	...	475,693,000	...	4,332	14	2
Saturn	...	872,135,000	...	10,759	5	16
Uranus	...	1,753,851,000	...	30,686	17	21
Neptune	...	2,746,271,000	...	60,118	0	0

58. *Size of the Planets.*—The relative size of the planets was also known before the actual size was determined, but when once the distances were actually determined, then the relation between the relative and actual size was also easily obtained, because when we know the distance, we need only measure the angle under which we see the disc of the planet, or its apparent size, and can then readily calculate what must be the dimensions of a body which subtends such an angle at such a distance. The size of the planets being once determined, we can then readily estimate their relative volumes, and their mass or weight in relation to their volume, which, we have already seen, is termed the density of the body. This mass is determined by the law that the attraction of a body such as the earth upon the moon varies

directly proportionally to the product of their masses, and inversely proportionally to the square of their distances. The density of the earth, therefore, or the relation between its mass and its volume being determined, it becomes a simple matter of calculation to determine the same for the other planets; and this is specially easy in the case where there are satellites accompanying the planet, since their distances and periods of revolution furnish the requisite data.

The following table exhibits the relative sizes of the various planets in diameter, measured in miles, and also the relative volume or space occupied by the planet in terms of the earth's volume, which is taken as unity; also the relative mass or weight, and the density of each of them, as compared with the earth, which in each case is taken as unity:—

	Diameter in Miles.	*Volume.*	*Mass or Weight.*	*Density.*
Mercury ...	2,962	0·05	0·07	1·24
Venus ...	7,510	0·80	0·79	0·90
Earth ...	7,901	1·00	1·00	1·00
Mars ...	4,920	0 14	0·12	0·96
Jupiter ...	85,390	1,387·00	300·00	0·20
Saturn ...	71,904	746·00	90·00	0·12
Uranus ...	33,024	72·00	13·00	0·18
Neptune ...	36,620	94·00	17·00	0·17

From this table it will be seen how very much larger the four outlying planets of the system are when compared with the four which lie nearest to the sun, and how far they exceed the latter planets in their volumes. The mass or weight, however, is not in proportion to this volume, because the density of the outlying planets is much less, and seems to increase as the planets lie nearer to the sun. If we wish to obtain the actual weight of the planets in tons, or any other standard weight, we have only to multiply the weight of the earth in tons (and which is, in round numbers, 6,000,000,000,000,000,000,000 tons), by the figures given in the third column for the respective planets, and we shall obtain it at once. In the same way, by multiplying

the figures in the column marked "density" by 5·45, which is the density of the earth as compared with water, we can obtain the density of any of the planets measured by the same standard, and which we call the specific gravity.

59. *Planetary Orbits.*—We have already seen that the planets move round the sun in curvilinear orbits, but these orbits are not perfectly circular, but nearly, if not quite, elliptical. The sun is, therefore, not in the centre of the orbit, but in one of the foci of the ellipse, and the motion of the planet in its path, in consequence of this, is not perfectly uniform, but grows swifter as it approaches the sun, and slower as it recedes from it. These results flow, as a natural consequence, from Newton's discoveries regarding the existence of universal gravitation, but long before his time they were embodied from actual observation in certain laws, which are called, after their first enunciator, Kepler's laws. They may be stated thus—

(1.) Each planet describes round the sun an orbit of elliptical form, and the centre of the sun occupies one of the foci.

(2.) The areas described by the radius-vector (or imaginary line which joins the centre of the sun and the planet) are proportional to the time occupied in describing them, so that equal areas are passed over in equal times.

(3.) The squares of the periodic times of the revolutions of the planets round the sun are proportional to the cubes of their mean distances, so that if the squares of the mean times are divided by the cubes of the mean distances, the quotient will be the same for all the planets.

If the planets were only acted upon by the sun, or if we consider the case of one planet and the sun alone, these laws would hold rigidly true; but we have already seen that every mass of matter acts upon every other mass in the universe, and in consequence of this, the various planets act and re-act upon each other, and introduce variations into their motions in their orbit, which are therefore subject to continual change, both in their

periodic times and mean distances. If we take the case of the earth, the planets which lie within its orbit, and nearer to the sun, tend to increase the force of attraction of the sun, and therefore tend to diminish the size of the earth's orbit, and decrease its periodic time, while those which lie without its orbit tend to produce an opposite effect. The relative positions of the planets are also continually changing, and the effects which they produce, therefore, are continually varying also. This variation also extends to the inclination of the orbits of the planets to the plane of the ecliptic, and to the satellites as well as to their primaries, because it will be easily seen that so long as the disturbing body is revolving in that part of its orbit which lies below the plane of the ecliptic, it will also tend to draw downwards from its plane of undisturbed revolution the body upon which it acts; and when the disturbing body reaches that part of its orbit which lies above the plane of the ecliptic, this action will be reversed. The whole of the variations which these mutual actions, however, introduce into the motions of the planets are confined within certain well-defined and narrow limits, and are recurrent during long periods of time; so that unless there is a resisting medium in space, which will retard the motion of the planets in their orbits, and thus cause the nature of the path which they describe round the sun to be not re-entering curves, but spirals, the harmony and stability of the solar system will be undisturbed. We shall afterwards see that there is strong reason to suppose that such a resisting medium does exist, which will ultimately cause the planets to fall into the sun.

60. *The Earth.*—Of all the planets, we know most in regard to the nature and structure of the earth, because we dwell upon its surface, and can analyse and examine the materials of which it is composed. We may take it, therefore, as a specimen of the planets, and enter more fully into details in regard to its shape, density, motions, and the changes which occur upon its surface,

both in regard to its rotation round its axis and round the sun, and in conjunction with its satellite, the moon.

The study of chemistry has enabled us to determine the number and relationship of the various elementary substances out of which the crust of the earth is composed, and the spectroscope has placed in our hands a means by which we can learn that the same materials are found in the sun, and even in the fixed stars, which lie far beyond the bounds of the solar system; so that we are enabled from analogy to infer a common origin for the various members of the solar system, and from the changes which we see occurring on the surface of the earth, we can determine, within certain limits, what may be occurring on the surfaces of the other planets.

61. *Figure of the Earth.*—The proof that the earth is a globe, and not a plane, may be derived in any of the following ways—

(1.) When we watch a vessel sailing out to sea, we first lose sight of the hull, and then of the masts; and in the same way, when a vessel is nearing land from the open sea, the highest mountains first come in sight, even when far removed inland from the shore, and the beach last of all.

(2.) When at sea, the horizon is always bounded by a circular line, and that line is, on any clear day, far within the limit of vision, and increases in size as any additional altitude is reached.

(3.) The shadow of the earth when the moon is eclipsed is always seen to be round, and we should naturally infer it to be so, because all the other members of the solar system exhibit round discs.

(4.) Whenever a portion of the earth's surface is measured by triangulation, the sum of the three angles always exhibits an excess over two right angles, which would not be the case if it were a plane, and not a sphere. This increase in measurement over two right angles is called the spherical excess.

(5.) If observations be made on different points on the

surface of the earth, at some distance from each other, of the stars which are in the zenith at these various points, it will be found that the imaginary straight lines which join the point of observation with the zenith are not parallel to each other, and the surface of the earth must therefore be a curved surface, and not a plane.

62. *Exact Figure of the Earth.*—By means of the observation of these zenith distances, as well as by experiments with the pendulum, it has been ascertained that the exact figure of the earth is an oblate spheroid, with the shorter axis from pole to pole, and the longer through the equator. The exact size is—

Equatorial Diameter	...	41,848,380 feet.
Polar Diameter ...	...	41,708,710 feet.

Recent researches, based upon accurate measurements of arcs of the meridian, have also brought to light the fact that the equator, or imaginary circle which girds the earth at its largest diameter, is not quite round—the equatorial diameter from 14° 23′ East, 194° 23′ East of Greenwich, being 41,852,864 feet long, while the diameter at right angles to it is only 41,843,896 feet, or about two miles shorter.

63. *Rotation of the Earth.*—In addition to the motion of the earth round the sun, it has also a motion of rotation round the line which passes from pole to pole, or through its shortest diameter. The time of this rotation is once in every 23 h. 56 min. 4·09 sec., measured by the departure of any meridian from a star and its return to it again; but when measured by the mean motion of the sun's return to the meridian, it is rather longer in consequence of the earth's motion in its orbit, and is exactly twenty-four hours. This constitutes the difference between a mean *solar day* and a *sidereal day*. The rotation of the earth upon its axis, which causes it to present alternate sides to the sun, round which it revolves in its orbit, makes the alternation of day and night. If the axis of rotation of the earth were at right angles to the plane

of the ecliptic, the day and night would always be equal in every latitude; but as it is inclined to that plane at an angle of $23\frac{1}{2}°$, and as the direction of this axis of rotation always remains practically in the same relative position in space, or parallel to itself, it is inclined *towards* the sun in one position in the orbit, and *from* it in another, so that the alternate poles of the

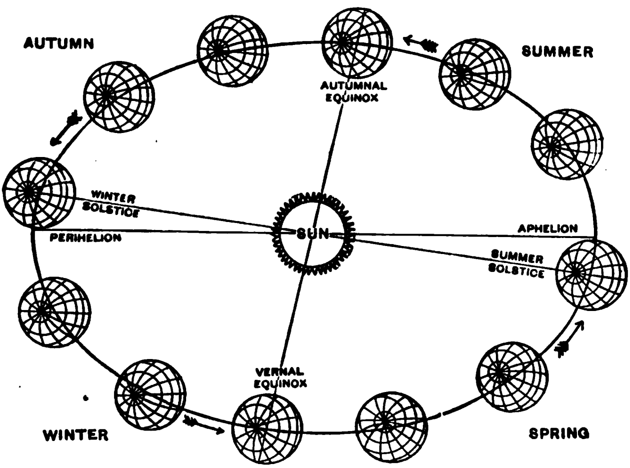

Fig. 1.—The Earth in its Orbit round the Sun.

earth are sometimes more illuminated than at other times. This will easily be seen by reference to Fig. 1, which represents an imaginary view of the earth in its various phases of revolution round the sun.

The imaginary lines drawn upon the surface of the earth represent the circles along which we measure *latitude* and *longitude* from a given meridian, which in this country is the meridian of Greenwich. Latitude is measured along the circumference of a great circle, the plane of which passes through the centre and poles of the

earth, and is determined in degrees, of which 90° extend from the equator to the pole, thus dividing the circle into four divisions of 90° each. In consequence of the earth being flatter at the poles than the equator, the degree of latitude varies in length at the pole and equator, being longer at the pole and shorter at the equator. In England, in latitude 52°, the length of 1° of latitude is 364,951 feet. The great circle which passes round the centre of the earth mid-way between the poles is called the *equator*. This circle is divided into 360°, which are measured up to 180° either way, east or west, from Greenwich. On either side of this equatorial line, and parallel to it, at the distance of 23½°, are the *Tropics of Cancer* on the north and *Capricorn* on the south. These mark the highest points towards the poles at which the sun is ever vertical, or in the zenith; and at the same distance from either pole we have two parallel lines, or circles, which are termed the *Arctic* and *Antarctic* circles, which mark the extreme limit at which the night and day cease to depend upon the rotation of the earth entirely, so that at the poles the year is made up of only one day and one night, each of six months' duration. These lines divide the surface of the earth into five zones, which are called frigid (two), temperate (two), and torrid (one). As the circles are all parallel to the equator, and become smaller and smaller as we approach the poles, it is obvious that the degree of longitude also decreases in length as we get farther away from the equator. At the equator the degree of longitude is about 69½ miles. When the latitude and longitude of a place are known, its exact position on the surface of the earth can be determined. At the equator the day and night are always equal, viz., twelve hours each; but as we go north or south, towards the poles, they vary in length with the season of the year, so that the earth's surface on either side of the equator may be divided into two zones, in one of which—that nearest the equator—the days and nights are measured by days, and beyond this by months. The variation depends upon

the position of the earth in its orbit, day and night being equal on all parts of the earth's surface at two points in the orbit, which are termed the *Vernal* and *Autumnal* equinoxes.

The rotation of the earth can easily be made visible to the eye by observing the motion of the stars or the sun from any fixed meridian, or by the swinging of a heavy ball, to which is attached a pointer, from a long wire. The line of motion of this pendulum being in a fixed plane, the earth moves round beneath it, and at the poles would describe a complete circle in twenty-four hours. It can also be observed with a gyroscope, the axis of which, when in motion, preserves a fixed position in space; and a star observed in the direction of the axis of the gyroscope remains in that position, while its direction with regard to the earth changes, showing it is the earth, and not the star, which is in motion.

64. *The Seasons.*—The four seasons—*spring*, *summer*, *autumn*, and *winter*—depend, like the variation in the length of the day and night, upon the inclination of the axis of the earth's rotation to the plane of the ecliptic, and also to a smaller extent upon the inclination of the plane of the earth's orbit to that of the ecliptic, and are a consequence of the revolution of the earth round the sun. In looking at Fig. 1, we see that as the earth leaves the autumnal equinox, in the northern hemisphere, the axis of rotation of the earth is continually being turned farther away from the sun, so that a larger portion of the hemisphere is in darkness, and the nights, therefore, increase in length until the winter solstice. In any given position in the northern hemisphere also, the height at which the sun will be seen above the horizon continually decreases up to this point. From the winter solstice to the vernal equinox, the changes take place in the opposite direction, and when the latter is reached day and night are again equal. From the vernal equinox to the summer solstice the length of the day is continually increasing, and the angle above the horizon at which the sun is seen increases

also. At the summer solstice the whole of the arctic circle is so illuminated that the rotation of the earth never removes any part of it out of the sunlight, and the sun never sets on every part of it until the autumnal equinox is again reached. In the southern hemisphere the seasons are exactly opposite to the northern hemisphere—the northern winter is the southern summer, and spring corresponds to autumn.

65. *The Earth's Orbit.*—In consequence of the form of the earth's orbit not being circular, but elliptical, the earth is nearer to the sun at one period of its revolution than at another. When at its greatest distance, it is about 92,965,000 miles from the sun, and we say it is in *aphelion*; when nearest to the sun, it is only 89,895,000 miles distant, and we say it is in *perihelion*. The mean distance is about 91,430,000 miles. The earth is in perihelion shortly after passing the winter solstice, and is, therefore, nearer to the sun during the northern winter than during the summer. This is reversed in the southern hemisphere—the sun being nearest during the summer and farthest away during the winter. The time required by the earth to perform one revolution in its orbit determines the length of the year. The year is 365 days, 6 hours, 9 minutes, 9·6 seconds. This determination is made by ascertaining the time between two successive conjunctions of a fixed star with the sun, and is called a *sidereal year*. A *solar year* is 20 minutes 23·55 seconds less, and is measured by two successive passages of the vernal equinox, which, as we shall afterwards see, is continually retrogressing, so that it appears to meet the sun, and thus makes the year appear shorter.

If we measure the length of the year by two successive passages of the aphelion or perihelion point, we shall find the year 4 minutes 39·7 seconds longer than the sidereal year, because these points have a motion forward in the direction of the earth's motion, and so tend to increase the year, which is then called the *anomalistic year*. The elliptical form of the earth's orbit causes the motion

of the earth round the sun to vary in speed, because the radius-vector, or imaginary line joining the centre of the sun and earth, sweeps over equal areas in equal times. Its motion is therefore slowest when farthest from the sun, and this causes the relative length of the seasons to vary. If the solar and anomalistic years were equal, the seasons would always occur in the same part of the earth's orbit; but as they differ in length, the line of *apsides*, or line which joins the aphelion and perihelion points, slowly changes its position, at a rate which will cause it to perform a complete revolution in about 21,000 years, so that in about half that time the earth will be nearest to the sun in the northern summer, which is the reverse of the present position, and our autumn and winter will then be longer than they are now, and our spring and summer shorter. Since the solar year does not contain an exact number of solar days, there is in each year nearly a quarter of a day left over, which, in our calendar, has to be corrected by the addition of an extra day in February once in every four years, which we call *Leap Year.* This addition, however, over-corrects the time by about three days in 400 years; and to arrange this, Pope Gregory adopted a plan of determining which year should be leap year, by means of which only 97, instead of 100, will occur in 400 years, and the error in the 400 years will, therefore, only be about $22\frac{1}{3}$ seconds, or one day in 3,866 years.

In consequence of the attraction of the other members of the solar system, the shape of the earth's orbit is slowly changing its degree of eccentricity, and at the present time is more nearly a circle than it was about 210,000 years ago, when the maximum variation reached about $\frac{1}{13}$th of the present distance of the earth from the sun. The present eccentricity is only $\frac{1}{60}$th of this quantity, and will slowly decrease to about $\frac{1}{90}$th, when the minimum will be reached, and the change slowly occur again in the opposite direction. This change in the maximum and minimum distance of the sun must alter the intensity of

the seasons in the arctic and temperate zones to an enormous degree, especially when the position of the earth in its orbit causes the summer solstice to coincide with the perihelion, as it does at the present in the southern hemisphere, and may have been one of the causes which produced the great variations in climate which are revealed in these zones by the progress of geological discovery.

66. *The Moon.*—As we have already seen, the earth is accompanied in its journey round the sun by one satellite, the moon, which, on account of its proximity to the earth, appears, next to the sun, to be the largest and most prominent object in the sky. It makes one revolution round the earth in 27 days, 7 hours, 43 minutes, 11½ seconds, and makes also one revolution on its axis of rotation during the same time, so that we only see one side of the moon, as the same face is turned continually towards us. The moon's axis of rotation is, however, like that of the earth, inclined at an angle to the plane of its orbit; and its orbit being elliptical, the motion of the body is not uniform, so that we sometimes see more of one pole than the other alternately, and sometimes more of the eastern, and then of the western edge. This is termed *libration* in latitude and longitude. The plane in which the moon revolves round the earth is also inclined at an angle of 5° to the plane of the earth's motion round the sun, and as the changes in the position of the moon's orbit, with regard to the earth, vary very rapidly, we have many different phases presented during the year.

67. *Phases of the Moon.*—The most familiar changes are those which the moon presents in regard to its degree of illumination by the sun in its monthly journey round the earth. These will be most clearly seen by reference to Fig. 2, where we have the appearance presented by the moon, both as seen in a bird's-eye view of its orbit and from the surface of the earth. The first of these is seen on the inside circle during every quarter of its revolution,

and the latter delineated in the outside circle. As seen from the sun, the degree of illumination is always the same, but from the earth within the orbit it varies from total darkness at new moon, through every degree, to full brightness at full moon, and waning from this point to new moon again. The inclination of the moon's orbit to

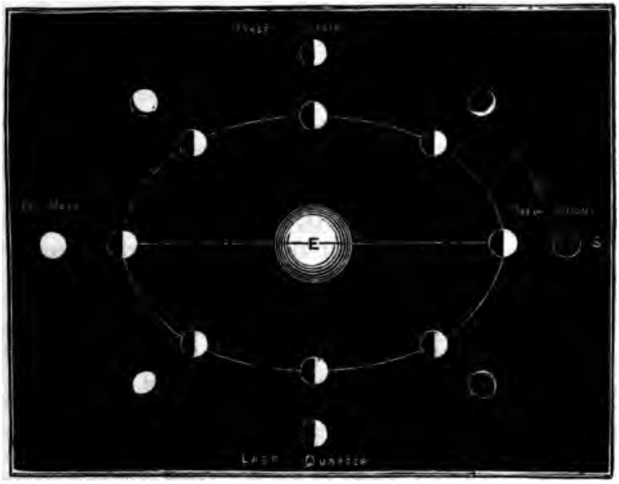

Fig. 2.—Phases of the Moon. E, Earth; S, Sun.

that of the earth causes the moon to be illuminated even when the earth is between the sun and moon, except at those times when the moon's *nodes*, or points where the orbits cross, come in the same straight line which joins the centre of the earth and sun, and we then have the phenomena of eclipses. If this occur at the full moon, we have an eclipse of the moon, because the shadow of the earth is projected on to the surface of the moon; and if at new moon, an eclipse of the sun, because the *dark body of the* moon hides the rays of the sun, and

the shadow of the moon is projected on to the earth. Partial or total eclipse depends upon the position of the moon in regard to the eccentricity of its orbit, and the exact degree of coincidence of the three bodies in regard to a straight line.

68. *Distance of the Moon.*—The distance of the moon from the earth can be easily determined, because being so near to the earth, there is a sensible change in the position which she occupies against the background of the sky, when seen from two distant positions on the surface of the earth. The distance between these two stations being known from the dimensions of the earth, and the angle between them and the centre of the moon—or, what is the same thing, the angle which the line joining the centre of the moon and the observing position makes with the zenith of the place—being known, we can easily calculate how far distant the moon is from the earth. We have already seen that this distance varies, because the orbit is not circular, but elliptical. The greatest distance, which we call the point of *apogee*, is 251,947 miles, and the nearest, or *perigee*, is 225,719 miles. The diameter of the moon is about 2,153 miles, so that it is about forty-nine times less than the earth in volume.

69. *The Tides.*—The preponderating attraction of the earth keeps the moon in its orbit, but the earth is also influenced by the moon in many ways. The shape of the earth being not a perfect sphere, but larger at the equator than at the poles, the excess of matter accumulated there is, in conjunction with the sun, unequally attracted by the moon, and causes the *precession of the equinoxes*, which we have already noticed. The most important action is, however, upon the water which covers a large portion of the earth, and this causes the tides. When the moon attracts the earth, the water is attracted also, and tends to leave the earth or draw nearer to the moon, both in the direct line which joins the moon and earth and in a tangential direction. When the sun and moon are on the same or opposite sides of the earth, as at the

new and full moon, then the action is greatest, and a mound of water is raised above the general level of the ocean. The highest elevation of this tidal wave is nearly along the line which joins the centre of the earth and moon. It therefore remains fixed while the earth revolves beneath it, and thus every part of the ocean is disturbed by this tidal wave once in twenty-four hours. The attraction of the moon, however, is greater upon the earth which lies nearest to it than upon the water on the opposite side of the earth, and as a consequence, while the water is piled up underneath the moon's meridian, the earth is also drawn towards it, and leaves the water behind, which, being lighter, tends to produce an equilibrium of the system, and there is, therefore, a tide produced on the opposite sides of the world at the same time. The tides which are produced by the combined action of the sun and moon are called *spring tides*, and always occur about three days after new and full moon. The *neap* tides, which are always lower, occur about the same time after the quadratures. The ellipsoid of water, which is formed upon the earth's surface by this attraction, always presents its longer axis to the moon, and as the earth is revolving within it, it produces an action like that of a friction break upon the globe, and tends to retard its rotation, and thus to reduce the speed of the earth, and lengthen the duration of the day. Recent researches in astronomical physics point to the fact that in the remote past the earth and moon were once much nearer to each other, and their mutual action therefore stronger, and the tides much higher and more errosive in their action—a fact to be remembered in the interpretation of geological phenomena. The action of the tides will tend to retard the rotation of the earth until the day is lengthened out to the same period of time as the revolution of the moon round the earth, and the only tidal action will then be that produced by the difference between the solar and lunar attraction. The lengthening of the day will also account for the dis-

crepancy between the observed and calculated position of the moon, which is known as the acceleration of its mean motion.

70. *The Surface of the Moon* can be observed with greater ease than any other member of the solar system,

Fig. 3.—A Lunar Landscape.

because it lies nearest to the earth; and with the most powerful telescopes can be seen as distinctly as if viewed with the naked eye at a distance of only about 200 miles. A more desolate landscape cannot be imagined. The plains are ancient sea-beds, which are all dried up; the mountains volcanoes, which have long been extinct, and which rear their barren summits to a height which, for the size of the moon, are much higher than any terrestrial mountain, and attain even 27,000 feet, as measured by

their shadows. Many of the craters are circular, with rugged mountain walls surrounding them, and enormous cracks and fissures are distinctly seen in the lunar surface, telling of earthquakes and upheavals in the ages long gone by. Fig. 3 gives a good idea of what the appearance of a lunar landscape must be in one of the mountainous regions. The absence of air and water renders the surface subject to very great changes in temperature. When the sun is shining upon it, the heat is probably far hotter than the temperature of boiling water, probably at least 600° Fahr.; and when his rays are withdrawn, the cold is so intense, from the radiation of the heat into space, that it is probably far below the lowest temperatures that ever exist upon the surface of the earth, or possibly that can be even artificially produced.

CHAPTER III.

THE PLANETS AND MEMBERS OF THE SOLAR SYSTEM OTHER THAN THE EARTH.

71. *The Physical Condition of the Planets.*—As we have already seen, the earth and moon are not the only members of the solar system, but they may be taken as types or examples of the probable nature of the other members, both as regards the materials out of which they are formed, and the changes which they have undergone during the past ages of their existence. We shall see in a future chapter they have, in all probability, had a common origin, and even since their separate condition was determined have been in an incandescent state, during which they were self-luminous; and among the more volatile constituents existing as gases in the surrounding atmosphere, just as upon the surface of the earth we

have water, vapour, and clouds, as well as air. Although we cannot examine the surfaces of the more distant planets in the same way and with the same distinctness as we can examine the surface of the moon, we can nevertheless trace the clouds floating in the planetary atmospheres, and in the case of one, at least, observe the accumulation of snow at the poles, the same as in our own arctic and antarctic regions.

The different distances at which the planets are situated from the sun make an enormous difference in the quantities of light and heat which they receive, and this, in turn, must alter the conditions upon the surface; unless, indeed, in the case of the larger and outlying members of the system, their own internal heat arising from their enormous mass is greater than in the smaller planets. They have also very different conditions, arising from their different times of rotation, the inclination of their axis of rotation, and other peculiarities which can only be generally noticed in detail.

72. *Mercury*, the planet lying nearest to the sun, of which we have certain evidence, is so lost in the solar light that it is extremely difficult to make accurate observations. Athough its mean distance from the sun is only 35,393,000 miles, its orbit is more elliptical than that of any other member of the system, and when farthest from the sun, is 15,000,000 miles farther than when nearest to it. This is about five times greater than the difference of least and greatest distance of the earth from the sun, and must make an enormous difference in the heat and light received when in the two positions. The inclination of the axis of rotation to the plane of its orbit is much greater than that of the earth; and although it performs one rotation on its axis in about 24 hours 5½ minutes, the relative length of the day and night during different periods of the year is much more variable than upon the earth. The length of the year is 87 days, 23 hours, 15 minutes.

73. *Venus* moves in an orbit which, unlike that of Mercury, has very little difference between its greatest

and least distance from the sun, being very nearly circular. The mean distance is about 66,131,000 miles. In its revolution round the sun it approaches nearer to the earth than any other planet, being, when at its nearest position, only 23,309,000 miles distant. When in the intermediate positions, where its light is not lost in the blaze of sunlight, it is the brightest object in the heavens except the moon and sun, and it is alternately the morning and evening star. Its light is so brilliant that it frequently casts shadows on the surface of the earth, and its phases, which are similar to the moon, are frequently quite distinctly seen even with the naked eye. Like the moon, when in certain positions with regard to the earth, it passes over the disc of the sun, and this *transit of Venus*, as we shall afterwards see, forms one of the best means of determining the distance of the sun. The inclination of the axis of rotation to the plane of the planet's orbit is very great; and this must make a very great difference between the summer and winter climates in both hemispheres, as they are alternately exposed to a six months' night and day of far greater heat and cold than our own earth, and during both summer and winter the sun at the equator hardly rises above the horizon. The mean length of the day is 23 hours, 21 minutes, and 23 seconds, but it is very variable in length during the different seasons on different parts of the planet. The year is 224 days, 16 hours, 48 minutes.

74. *Mars* is the first of what are known as the exterior planets, because its orbit lies entirely outside that of the earth, and farther away from the sun. The orbit of Mars is far more elliptical than that of the earth, so that when nearest to the sun, the planet is only 126,341,000 miles, and when farthest away, 152,284,000 miles, and the enormous difference between these two extremes causes a very great variation in the amount of heat and light which it receives at different seasons of the year: all the more so, because the summer of the southern

hemisphere occurs when the planet is near its perihelion. The year is 686 days, 23 hours, 31 minutes long, and the length of the day very similar to our own—24 hours, 37 minutes, 22 seconds. The inclination of the axis of rotation to the plane of the planet's orbit is 28° 51′, so that the seasons from this cause are something like our own, but on account of the greater ellipticity of the orbit, they are not so equal as on the earth, and also much longer, on account of the greater length of the year.

The surface of Mars is evidently diversified by land and water, and during the winter the snow can be easily seen accumulating at the poles, and melting away or growing less during the summer. When nearest to the earth, it is only 62,389,000 miles distant, so that there is a great difference in the apparent size of the planet when viewed from the earth at different times. Recent discovery has determined that Mars is accompanied by two small moons.

75. *The Asteroids.*—As we have already seen (57), the discovery of Bode's law led to the assumption that a planet, or planets, must have existed at some time in the intermediate space between the orbits of Mars and Jupiter; and when careful observation was made, it led to the discovery of a large number of smaller planets occupying this space. About 222 are now known and named, and it is quite probable that a still larger number may yet remain undetected, on account of their very small size, since the largest is only about 228 miles in diameter, and they vary in size downwards to 50 miles in diameter. Their orbits are all very elliptical, and the plane of their motions is inclined in some cases as much as 34° to that of the ecliptic, while in others it is almost in the same plane.

Nothing is known respecting their rotation on their axis, but Herschel observed that, from the great variation in brightness which they sometimes exhibit, it almost seems as if they presented flattened surfaces, and therefore partake of the nature of angular fragments rather

than globes: as if they formed portions of a larger planet, which at some time or other had been broken up; and it appears quite impossible, from the wide area over which they are scattered, and the inter-crossing of the lines of their orbits, that they should not be in some way related to each other.

76. *Jupiter* is the largest planet in the solar system, possessing an equatorial diameter of 85,390 miles, so that it exceeds the earth in volume nearly 1,400 times. It revolves at a mean distance of 475,693,000 miles from the sun, and is accompanied by four moons, or satellites, which revolve round it in orbits very nearly coincident

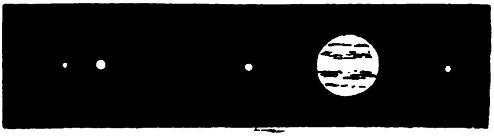

Fig. 4.—Jupiter and its Moons.

with the plane of the equator, so that they frequently pass over the surface of the planet, when they appear as black spots on the luminous disc, or else are eclipsed behind the body of the planet. Fig. 4 gives a good representation of Jupiter and its moons, as seen through a telescope.

The rotation of Jupiter on its axis is very rapid, being only 9 hours, 55 minutes, 28 seconds, so that the day is less than half the terrestrial day; and as the axis of rotation is very slightly inclined to the plane of the orbit, the length of the day during the small variation in the seasons is almost the same on all parts of the surface. The same cause renders the climate nearly the same all the year round, except just at the poles, where the day and night are six years each in duration. The length of the year is 4,332 days, 14 hours, 2 minutes. When viewed with a large telescope, the flattening of the globe

at the poles, arising from the rapidity of rotation, which causes the globe to assume the spheroidal form—the same as the shape of the earth—is distinctly seen, and the appearance of the equatorial regions, with their cloudy strata, can also be distinguished. It is quite possible that the dense steamy atmosphere by which Jupiter is surrounded masks the actual size of the planet, and that if the dimensions of the solid globe were actually known,

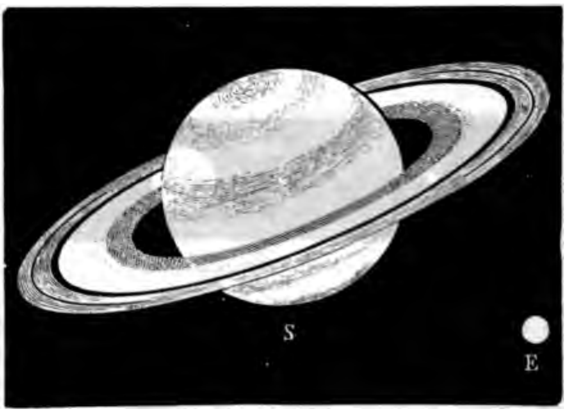

Fig. 5.—Saturn and its Ring.

it would modify our present idea of its density, which we regard as less than one-quarter of that of our own earth.

77. *Saturn* is one of the most glorious objects which can be seen by the telescope, and occupies a unique position amongst the members of the solar system. It revolves in an orbit at a mean distance of 872,135,000 miles from the sun, and the axis of rotation is inclined at an angle of 26° 59′ to the plane of revolution, so that, unlike Jupiter, it possesses seasons. It has a mean diameter of 71,904 miles, and therefore exceeds the volume of the earth above 746 times. It is the lightest

body in the solar system, being only $\frac{12}{100}$ths of the density of the earth, and is, therefore, lighter than cork. It rotates on its axis once in 10 hours, 29 minutes, 17 seconds, and is attended by eight moons, which revolve in orbits which are very nearly coincident with the plane of the planet's equator, so that they are sometimes seen to move along the apparent edge of the rings, like golden beads on a silver thread. The rings are, however, the most wonderful appendages of Saturn, and probably consist of a vast cloud of very small moons, or satellites, which lie close together, and revolve round the planet in an orbit which is in the same plane as the equator. Fig. 5 gives a good idea of these wonderful bodies when seen through a good telescope. The comparative size of the earth is also seen at E. When viewed from the earth, the rings are continually changing their position with regard to the body of the planet, so that sometimes they are exhibited at one angle and then at another, and even in one position are so foreshortened that they only present the appearance of an exceedingly attenuated luminous line. With the most powerful telescopes they are found to consist of numerous concentric rings of different degrees of density and luminosity, and there seem to be indications that they are slowly concentrating towards the planet, and may possibly ultimately fall into the planetary surface, or become a satellite, if the continuity of the ring is broken from any cause. They form a splendid spectacle when seen from the earth, but it must be much more magnificent when seen from the body of Saturn, when these luminous rings will arch the sky during certain seasons with inconceivable grandeur. The year in Saturn is upwards of 10,759 days long.

78. *Uranus* revolves round the sun at a mean distance of 1,752,851,000 miles, and requires no less than 30,686 days, 17 hours, 21 minutes to perform one revolution. The inclination of the planet's equator to the plane of its orbit is very great, being 100° 20′; and it

is attended by at least four moons, which have this peculiarity: that they move in a retrograde direction, that is, opposite to that of all the other members of the solar system; but this anomaly probably arises from the very great inclination of their orbits to the plane of the ecliptic. The length of the day is unknown.

79. *Neptune*, which forms the outlying planet of the solar system, so far as is at present known, is situated at a mean distance of 2,746,271,000 miles from the sun, and is attended by one, or possibly more, moons, but the distance is so vast that our present telescopic power can reveal very little respecting them. Their motion is in a plane of great obliquity to the ecliptic, and possibly retrograde, like that of the moons of Uranus. The discovery of this planet was due to the fact that it exercised a disturbing influence upon Uranus, and its exact position, although unknown, was calculated by the two celebrated astronomers, Professor Adams and M. Leverrier, quite independently of each other. The record of this discovery is one of the most astonishing chapters in the history of astronomy, and affords a striking proof of the correctness of the theory of universal gravitation.

CHAPTER IV.

COMETS AND METEORITES.

80. *Appearance of Comets.*—Planets and their attendant moons, and even the brilliant rings of Saturn, are not the only members and features of the solar system. All these bodies revolve in elliptical orbits round the sun and round their primary planets in one direction, which *is from west to* east, with the exceptions we have already

l, and they all derive their luminosity from the :ted light which emanates from the great central of the system, the sun. Sometimes, however, a new of visitants appears in the heavens, some of which undoubtedly members of the system, but which do follow these general laws. They have received the of *Comets*, from streaming hair-like arance of the luminous tails by which they usually attended, ugh, as we shall wards see, this appage is not always ent. The comet, ver, usually con- of a bright portion, *ad*, which may be ared to a star surded by a luminous or mist, and somes containing a very it centre, which is d the *nucleus*. From head, and in a rary direction to sun, there usually ms a long luminous which widens out

Fig. 6.—Structure of Comet.
(*Telescopic View of the great Comet of 1881, June 27, midnight.—W. F. Denning.*)

t recedes from the head, and generally is curved the blade of a scimitar. Fig. 6 represents the arance of the head of the great comet of 1881, en at midnight on the 27th of June. In this the head was found to consist of a series of entric luminous envelopes, which were turned back the arc-shaped centre, and seemed as though they driven rearward by the velocity of motion, which in cases at the perihelion has exceeded 1,000,000 miles

per hour. In the case of Donati's comet in 1858, the tail exceeded 30,000,000 miles in length.

81. *Orbits of Comets.*—The orbits of comets are far more elliptical than those of any of the planets, and in some cases are parabolic curves, which indicate that they are not members of the solar system, so far as we know, because they probably never return, and we cannot say from whence they come. Comets with elliptical orbits return at definite times, although the period varies very much in different instances. About nine of them have been observed to return more than once in periods varying from 3½ to about 77 years, while there are several which are termed *long period* comets, to distinguish them from these *short period* comets, whose time of return varies from 2,000 to 10,000 years. These comets follow the same laws as planets in their motion, by moving with the greatest rapidity when nearest to the sun, and slowest when farthest away. Indeed, when at their aphelion point, they must all but stand still, and probably shrink in dimensions when so far removed from the sun, since some of them pass far beyond the orbit of Neptune. As they approach the sun the rapidity of motion increases, and the activity and luminosity of the nucleus also become greater, as is evidenced by the appearance of new luminous jets and increased length of tail: and some of them pass so close into the solar blaze of light that they almost touch the surface of the sun, and must be raised to a temperature which far exceeds anything of which we have any conception. The comet of 1843 was visible in broad daylight when nearest the sun, and the comet of 1680, when in the same position, developed a tail 20,000,000 leagues long in two days. The inclination of the orbits of comets is at all angles to the plane of the ecliptic, so that while some of them seem to come in sideways, and cross the orbits of the planets in their course towards the sun, others seem to drop down from the zenith towards the sun, or come up from beneath the plane of the ecliptic, or in any intermediate position.

82. *Mass of Comets.*—The absolute quantity of matter contained in the largest comet is only small, as evinced by the effect produced upon them by other members of the system. In 1776 a comet passed amongst the moons of Jupiter, and although they were not disturbed in any way, the orbit of the comet was entirely changed, so that any fear of danger from collision with these bodies and the earth may be entirely dismissed. In the case of comets without nucleus, they, probably, consist of a mass of flaming vapour, probably (from recent spectrum observations) some compound of carbon, which is held together by the mutual gravitation of its parts, and is only slightly acted upon by the medium which exists in inter-planetary spaces. The theory, indeed, of a resisting medium in space is based entirely upon the retardation which has been observed in the case of Encke's comet, which performs its revolution in less time than formerly; and although we cannot detect its effect upon the planets, on account of their enormously greater mass, still the action is present, and will, in the course of long ages, retard their motion also, and cause their path to be a spiral, the termination of which is the sun.

83. *Meteors.*—In addition to planets and comets, there is yet another class of bodies which are now known to be members of the system. These are immense numbers of very small bodies, which vary in size from almost impalpable dust up to many tons' weight. They revolve in very elongated elliptical orbits, some of which cross the path of the earth's motion in space. They are quite invisible by even the most powerful telescopes, but when this meteor stream comes in contact with the earth's atmosphere, the motion of these small bodies is retarded by the friction of the air, and they are raised to incandescence, and thus become visible as luminous meteors. Sometimes these small bodies are found on the surface of the earth, and have even been picked up when still in a hot condition, but, probably, by far the largest number are dissipated into vapour by the heat. In certain positions

of the earth's orbit these meteoric displays are more numerous than at other times; and it has been discovered that one of these positions, which is reached by the earth in November, is always distinguished by an unusual number of these meteors during years which agree with the period of return of Biela's comet. They also appear always to emanate from a point in the heavens near to the constellation Andromeda, which is the point which corresponds with the position from which the comet approaches the sun, and they are sometimes therefore called *Andromedes;* but there are also other points from which, at different seasons, they appear to radiate, so that in the course of its orbit round the sun the earth probably encounters several meteor streams, or crosses the orbit in which they move, and as they are not equally distributed throughout the orbit, larger numbers are encountered at one time than another. It seems very probable, indeed, that all these meteor streams may correspond with the orbit of some comet, since this has been verified in several other cases besides that of Biela's comet. This discovery is one of the most remarkable that has been made in recent years, and may possibly, at some future time, throw new light on the nature and constitution of comets.

CHAPTER V.

THE SUN AS A GRAVITATING CENTRE.

84. *Size of the Sun.*—The sun far exceeds all the other members of the system by which it is surrounded in its immense size and weight, the enormous mass of which bends all the planets into their orbits, and at the same time illuminates and warms them with its light and heat.

So great, indeed, is the preponderating mass of the sun over that of all the other members of the system, when taken collectively, that even if they were all arranged on one side of the sun, and acting at their respective distances, the centre of gravity of the whole system would fall within the diameter of the sun. This diameter is

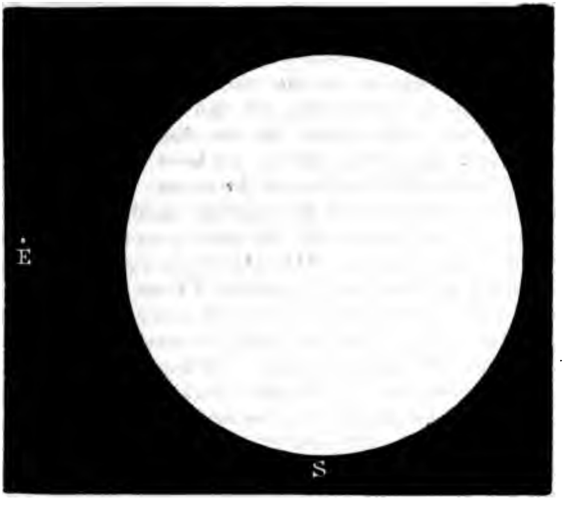

Fig. 7.—Relative Size of the Sun and Earth.

about 853,380 miles, so that the volume of the sun is 1,200,000 times that of the earth; but as the specific gravity, or relation between its volume and mass, is less than that of the earth, being only one-quarter as dense, it only exceeds the earth 300,000 times in weight.

Some idea of the comparative size of the sun and earth may be obtained by reference to Fig. 7, where we have the size of the sun represented at S, and the earth by the small point at E.

85. *Distance of the Sun.*—The distance of the sun is too great to be determined accurately, like that of the moon, by observation of the angle which the centre subtends with two different positions on the earth's surface, but it has been approximately ascertained by means of the observations made on the *opposition of Mars* and the *transit of Venus.* The observations on the planet Mars enable us, by measurements at the same station, when taken as the planet rises and sets, to determine the angle which the planet subtends with the same position when seen at the distance of the earth's diameter, and with this length as a base-line, we can calculate, by plane trigonometry, what must be the distance between the planet and the earth, just as we have already seen we can determine the distance of the moon. Since we know the relative distances of the various members of the solar system, we can, when one distance is accurately known, determine all the rest. Mars, however, never approaches the earth as near as the planet Venus, and hence the latter is the better planet to use for determining the distance between it and the earth, because, being nearest, the angle subtended is larger. When Venus is nearer the earth, however, it has the dark side of the planet turned towards the observer, because the orbit lies within the orbit of the earth; and it is only under the following circumstances that the observations necessary for determining the distance can be made. The planet, in conjunction with the sun, must be in one of its nodes, so as to pass, not over or under, but across the solar disc, appearing as a dark spot on the solar surface. Fig. 8 will make the method used more distinct than any description. If we have two observers at A and B on opposite sides of the earth, the dark body of Venus will be seen to cross over the face of the sun in two different positions, the observer at A seeing it pass along the line C D, and the one at B along the line E F; and since the sun has a circular disc, the two lines will not be of equal length, and as the planet will move with the same velocity, as seen from the two

stations, the difference in time taken to cross the sun will give us the position of the two chords E F and C D. If the distance A V, which is the distance from the earth to Venus, were equal to the distance V H, or of Venus from the sun, then G H would be equal to A B, which is the diameter of the earth; but we know that these two distances are not equal, but that, in round numbers, A V is

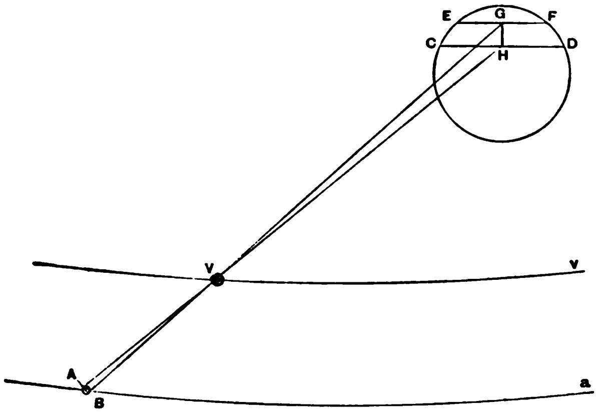

Fig. 8.—Diagram illustrating the Transit of Venus.

to V H as 28 to 72, and that the separation of these chords will bear the same proportionate relation to the diameter of the earth; and if we take the stations not too far from the poles of the earth, this separation will amount to 18,000 miles. When we know, therefore, the exact position which these chords occupy on the disc of the sun, we can measure the exact proportion which the line G H bears to the whole diameter of the sun, and this will give us the solar diameter in miles, and its distance will at once follow, because we can then calculate the exact angle the earth's semi-diameter would subtend at the same distance, and by plane trigonometry deter-

mine what is the exact length of the straight line between the centre of the earth and sun. This angle is not yet accurately determined, and the various methods which have been employed, including the observations made during the transit of Venus in 1874, seem to place the mean distance of the sun from the earth between 91,430,000 and 93,300,000, so that the figures given in our various astronomical tables and works must be considered as only approximate, and waiting confirmation or otherwise from the transit of Venus in 1882.

In actual practice, the distance of the sun and the chords of the arc cut off by the transit of Venus over its surface are not so easily obtained as above, because the question is complicated by the fact that both the earth and Venus are in motion, and not quite in the same plane, and the stations where observation can be made are not always in those positions which are best adapted for the purpose.

86. *Nature of the Sun.*—When viewed from the earth, the sun appears as a magnificent orb of glowing light, which, when above the horizon, causes all the other heavenly bodies to disappear in the luminous blaze of glory. It forms the great source of both light and heat to all the members of the system. From observations and comparisons made at the surface of the earth, it has been calculated that the intensity of sunlight at the solar surface is 190,000 times greater than that of a candle, 146 times that of the oxy-hydrogen light, and $3\frac{1}{2}$ times that of the most brilliant electric arc which can be produced. The heat which is given out by the sun exceeds all the powers of the mind to conceive. If employed to boil water, the whole heat given out in an hour would evaporate 700,000,000,000 cubic miles of ice cold water, and be equal to the heat generated by the combustion of a solid layer of coal ten feet thick over the whole solar surface, or to a combustion of 16,436,000,000,000,000 of tons of anthracite coal per second. The earth only receives about $\frac{1}{2,300,000,000}$th of the total radiation, but this

is the cause of the whole of the phenomenal activity on the surface of the earth; and if this were removed, a very short period would suffice to reduce the earth to a barren wilderness, devoid of life, and freeze the ocean to a solid block of ice. The surface of the sun appears to be composed of a glowing mass of incandescent gas, which is in constant motion, and amidst which incessant precipitation

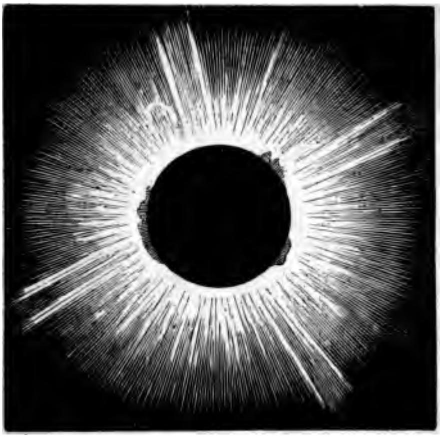

Fig. 9.—Corona of the Sun.

of more solid matter is taking place; and when an eclipse of the sun occurs, and the moon covers the disc of the sun, we can see the flaming gases like vast tongues of luminous fire stretching far out into space, while the whole region round the sun is enveloped in a *corona*, or blaze of radiating light. This corona, as seen during an eclipse, when the direct solar light is cut off by the dark body of the moon, is represented in Fig. 9. The whole surface of the sun, however, is not equally bright, and in the equatorial regions, and for some distance on either side, there are frequent appearances of dark *spots*, which

exhibit different phases as they are presented to the observer by the rotation of the sun on its axis in from 25 to 28 days. These spots appear to be vortices of gas, less luminous than the general surface of the *photosphere*, which is the term used to denote the brightest part, which

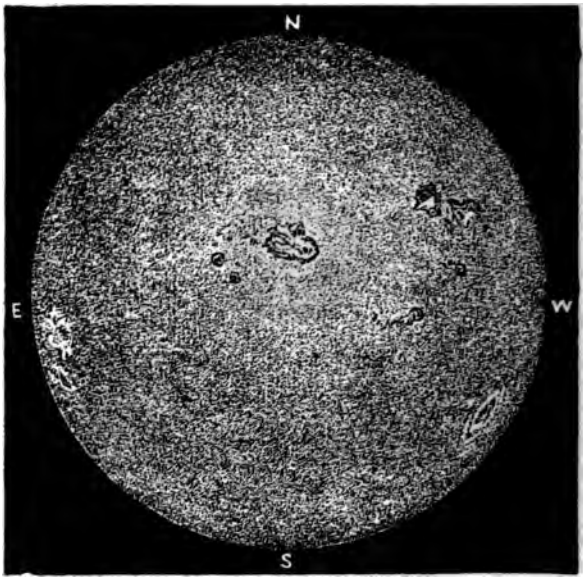

Fig. 10.—Sun Spots.

is like a cloudy atmosphere, only, unlike our earthly clouds, which are water vapour, these solar clouds are probably composed of precipitated metallic vapour. Fig. 10 represents the disc of the sun, as seen through the telescope, with a number of these spots visible on the surface; while the variation in brightness of the photosphere is represented by the mottled appearance over the whole area.

When the spots are seen through a very powerful telescope, the appearance is really wonderful. The whole region round seems to be in a state of the most violent agitation, and the luminous portions of the photosphere assume the most singular aspect, as though driven into

Fig. 11.—Magnified View of Sun-Spot.

vast cyclones of flaming gas. Fig. 11 is engraved from an accurate drawing of a very large spot. The number of these spots, and their size also, differ very much at different periods, and their recurrence appears in some way to be connected with the action of the planets upon the solar photosphere, and also seems connected with the magnetic phenomena which are exhibited at the surface of the earth in the aurora borealis and earth currents.

The application of spectrum analysis has conclusively

shown the existence of, at any rate, fourteen different metallic bodies in the atmosphere of the sun which occur on the earth, such as sodium, iron, magnesium, copper, zinc; and a number of others also probably exist, including such gases as oxygen and hydrogen.

87. *Cause of Solar Heat and Light.*—Many theories have been propounded to account for these phenomena, and probably none of them are altogether correct. That the source of the heat and light is not combustion, like that of coal or ordinary gas when burnt along with oxygen, is quite certain, because even if the sun were a mass of fuel as combustible as coal, it would be entirely consumed in about 5,000 years. The intensity of gravitation at the surface of the sun, which would impart a final velocity to a falling body of from 270 to 390 miles per second, depending on the direction of its motion, would cause any substance falling from space into the sun to generate a quantity of heat equal to from 4,000 to 9,000 times the same weight of coal; and hence it has been supposed that the fall of meteorites, of which the zodiacal light may be the evidence of a ring surrounding the sun, would keep up the supply of energy. The most probable cause, however, seems to be the slow concentration of the whole mass of the sun upon its centre, and this alone, without any accessory causes, would suffice to keep up the solar radiation by the production of sufficient heat, and yet within any period of human history reveal no diminution in diameter which could be detected by any means at our command. We shall afterwards see that there is good reason to suppose that this slow concentration is actually taking place, although the radiation may be assisted by the fall of various bodies into the sun—a fate which, in the long course of ages, will probably befall all the members of the solar system.

CHAPTER VI.

THE STARS AND NEBULÆ.

88. *The Starry Heavens.*—The solar system only forms a small part of the visible universe. Far beyond the limits of the orbit of the most distant member of this system lie the vast depths of inter-stellar space, into which we look when the setting of the sun permits us to see the numerous other luminous bodies by which they are tenanted. Taking the sun as the type of one of these *stars*, we suppose them to be self-luminous bodies, like the sun, and differing in size and brightness, not only on account of probable variations in their real size, but also on account of the different distances at which they are situated in regard to the earth; and although this distance is far too great to enable us to ascertain whether they are each attended, like our own sun, by a retinue of planets, still, analogy points to this as a reasonable supposition. It also seems to indicate that our sun is only one of the smaller stars; and if we were removed into the far distant regions of space, it would, when seen from such a distance, dwindle into one of the lesser stars, both in intrinsic splendour and magnitude.

89. *Motion of the Heavens.*—In consequence of the rotation of the earth upon its axis, the whole of the heavens, with all the multitude of stars, are successively brought within the field of view of observers situated on different parts of the earth's surface. Those stars which lie in the direction of the poles, about which the earth turns, appear to have the least motion, and in the exact zenith of the poles have none whatever; while those near the equator have the greatest motion, and appear to rise and set like the sun, and have a motion from east to west. The apparent vault of heaven in which these stars are situated we term the *celestial sphere*, and we divide

it into polar and equatorial regions, in the same way as we divide the surface of the earth. The great circle lying in the same plane as the earth's equator is called the *equinoctial;* and in a narrow region of the celestial sphere, on either side of this line, we see the sun and various members of the solar system moving and changing their positions with regard to the fixed stars, which form the background in the heavens, against which the planets are projected, according to the season of the year. The position which stars occupy in the celestial vault is measured in distance from a fixed point in this equinoctial line, just as we indicate places on the surface of the earth by distance from the meridian of Greenwich. On the celestial sphere we term this distance *right ascension*, and the fixed point is that occupied by the sun at the vernal equinox, which is termed the first point of Aries, because the constellation of that name occupies the background at that time. Right ascension corresponds to terrestrial longitude, and is measured in hours, minutes, and seconds, east from the first point in Aries, according to the time which is required to bring the given star into the meridian of the place of observation, just as we measure in degrees east of Greenwich on the surface of the earth. Celestial latitude is termed *declination*, and is measured from the equatorial or equinoctial line north or south to the pole. The degree of north or south declination commences from 0° at the equinoctial to 90° at the pole, and the declination of a star towards either pole being known, and its right ascension from the first point in Aries, we can at any time find its position when visible above the horizon.

That portion of the heavens which is visible during the night varies with the season of the year, because the earth in its revolution round the sun causes successive portions of the celestial vault to be presented to the eye. These various parts of the celestial sphere are called *constellations*, and have received various names based on fancied resemblances to terrestrial objects.

90. *Constellations.*—The constellations are divided into three groups, according as they lie in the line of the apparent path pursued by the sun in its annual round, or north or south from this line. *The Zodiacal Constellations*, which lie in the path of the sun, in the direction of his motion, are twelve in number—Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces.

The Northern Constellations are twenty-five in number—Ursa Major, Ursa Minor, Draco, Cepheus, Boötes, Corona Borealis, Hercules, Lyra, Cygnus, Cassiopeia, Perseus, Auriga, Serpentarius, Serpens, Sagitta, Aquila, Delphinus, Equuleus, Pegasus, Andromeda, Triangulum, Camelopardalis, Canes Venatici, Vulpecula et Anser, Cor Caroli.

The Southern Constellations are eighteen in number—Cetus, Orion, Eridanus, Lepus, Canis Major, Canis Minor, Argo Navis, Hydra, Crater, Corvus, Centaurus, Lupus, Ara, Corona Australis, Piscis Australis, Monoceros, Columba Noachi, Crux Australis.

The *Fixed Stars*, which are so called because they remain in the same positions in these constellations, are named after the constellation in which they are situated, with the prefix of a letter in the Greek alphabet, beginning with α, which indicates the first in brightness in that constellation. Thus α Lyræ denotes Vega, which is the brightest star in the constellation Lyra. β Lyræ is the second star in brightness, and so on in regular order. Sometimes the most brilliant stars have special names, such as Vega, just named. Sirius, Procyon, Arcturus, Aldebaran, Castor, and Pollux are also well-known stars.

91. *Distribution of Stars.*—The distribution of the stars in the vault of heaven is very singular and very unequal. In some places they seem crowded together in clusters, while in others they are very few and far between. The largest stars seem specially irregular in their distribution, but the smaller ones seem to increase in

number as they approach that portion of the heavens which is known as the Milky Way, on account of the immense multitude of stars causing the heavens in that region to shine with a faint white glow. In the immediate neighbourhood of this belt upwards of 18,000,000 are visible with the most powerful telescopes. In the whole of the celestial sphere about 6,000 stars of all magnitudes are visible to the naked eye, and as only one-half of this sphere is visible at once, we can never, under the most favourable circumstances, see more than 3,000 at one time. Some astronomers have thought it probable that those stars which appear to us the brightest are those which lie nearest to the solar system, and that they become more faint and dim as they increase in distance; also that they are most extended in those parts of the heavens where the numbers seem to be greatest, as in the Milky Way.

The portion of the universe to which our own system appears to belong seems to be extended in this direction, and divided into two principal branches throughout nearly its entire length; and the whole of the solar system seems to be moving in the direction of the constellation Hercules, so that the stars in that region are becoming farther apart, while those at the opposite side of the heavens are closing up and becoming more faint. In consequence of this proper motion, the real form of the earth's orbit is not an ellipse, but an immense spiral—like a distorted corkscrew which is described in space.

92. *Distance of the Fixed Stars.*—The distance of the nearest fixed stars is so vast that accurate determination becomes almost impossible, even when the base-line used to determine the horizontal parallax is the diameter of the earth's orbit, which is probably not less than 186,000,000 miles; and, therefore, if the angle subtended is less than 1″, the star must at least be not less than half this quantity multiplied by 206,265, or 19,172,645,000,000 miles distant. By the use of the micrometer, which enables the exact position of every star to be determined

in relation to the stars by which it is surrounded, it has been found that some of the fixed stars do change their position with regard to those which lie beyond them, when viewed from different parts of the earth's orbit; and in this way the parallax of many of the most important stars has been determined, and an approximate distance in miles calculated, but in no instance do they indicate a greater proximity than the figures already given. Many of them are far remote, so distant, indeed, that light, which moves with such velocity that it could traverse the entire circumference of the globe nearly eight times in a single second of time, may have taken thousands of years to reach this earth, and they would remain visible in the heavens thousands of years after their incandescence had ceased to exist.

93. *Multiple Stars.*—Our own sun appears to be isolated in space, or, at least, only surrounded by planets which have now ceased to be self-luminous; but there exist in the far-distant parts of the universe many instances where we have the singular spectacle of two, and even more, stars or suns, which revolve round each other, or round some common centre, in periods which vary from a few years to possibly many millions. From the motions of some of the visible stars also, there appears to be a high probability that there are also existing in space stars which have now ceased to be luminous, and only reveal their presence by the action which they have upon the luminous stars with which they are associated.

94. *Colour of Stars.*—In addition to the different physical condition which is manifested by these combinations of suns, there is also a great variation in the colour of the light which is transmitted from the various stars. They differ in many important particulars when examined by the spectroscope, which seems to indicate that they vary in the degree of temperature which is exhibited in the photosphere, or luminous surface; and this method of examination has even given strong reasons for supposing that many metals and other substances which are present

on the earth exist as gas in these far-distant orbs. They thus appear to have a constitution similar to that of our own sun. The light in many stars also is subject to considerable variation at different times, which range over both long and short periods. These stars are called *variable stars.*

95. *Nebulæ.*—In addition to the fixed stars, there is another class of bodies which exist in space, to which the

Fig. 12.—The Nebula in Orion.

name *Nebulæ* has been applied, because they exhibit not a bright distinct light, as if emitted from an incandescent solid, but a faint luminous glow, like that exhibited by an incandescent gas or luminous cloud. These singular bodies were originally supposed to be clusters of stars, which were situated at such a distance that our most powerful telescopes could not resolve them into individual stars; and in some instances this has proved to be the case. The use of the spectroscope has, however, conclusively proved that many of them are really vast masses of glowing or incandescent gas, which differ in

density in different parts; and there is strong reason to suppose that at any rate one of the gases present is hydrogen.

These singular bodies exhibit the most fantastic forms, some being drawn out into long luminous spirals, while others are arranged into ring-shaped or globular masses.

Fig. 13.—The Spiral Nebula in Canes Venatici (Messier, 51).

Some are so irregular that no words can describe their shape, while others seem to be diffused like a luminous mist round a central sun-like disc, in which case they are termed *nebulous stars*. Fig. 12 represents the nebula in the constellation Orion, and Fig. 13 the large spiral nebula in Canes Venatici; and these two examples will serve to show what a strange form these singular bodies assume. The discovery of these bodies has proved the existence of a nebulous fluid in space, and

given a considerably higher degree of probability to the nebular theory of the origin of the present condition of the physical universe.

CHAPTER VII.

UNIVERSAL GRAVITATION.

96. *The Law of Gravitation.*—We have already seen that all bodies which are situated upon the surface of the earth are subject to the attraction of the earth, and that were the earth a sphere, the whole of its attraction, when considered in reference to any body situated outside the earth, might be regarded as concentrated at its centre. The attraction of all bodies towards the earth will therefore vary as the product of their masses, and inversely as the square of the distance from the centre of the earth, so that the weight of any body upon the surface of the earth is equal to the mass of the earth multiplied into the mass of the body, and divided by the square of the radius of the earth. The same law holds good for all bodies, whether they are near to the earth or far from it in the infinite depths of space, and regulates or determines the weight of every planet and sun in exactly the same way as the smallest body upon the surface of the earth. When the laws of Kepler were first announced, they were only the empirical laws deduced from actual observation of the motions of the planets; but since the discovery of this grand law of universal gravitation, they are known to be the necessary result of its action, and the nature of the orbits of all the planets and satellites, and of the comets and streams of meteorites, are deduced from it with unerring accuracy. One peculiar feature of this universal law is that the attraction of bodies for each other is directly as their masses, quite independent of what the

real nature of the matter may be, so that, in proportion to their masses, all bodies are equally attracted, both towards masses of the same and of different kinds. In this way the attraction of gravitation is entirely different from either chemical or magnetic attraction. In consequence of this universal law, the whole of the members of the solar system are continually re-acting upon each other, and these re-actions introduce a series of changes and disturbances into the motions of the planets and satellites, which have taxed all the resources of mathematical analysis to determine, but which can always be shown to be in strict accordance with the law of gravitation, and form, indeed, the strongest proof of its existence.

97. *Masses of the Sun and Planets.*—According to the law of gravitation, the difference between the mass of any two bodies can be ascertained by the attraction which they respectively exercise upon any other body, and if we can find how far any planet is caused to fall towards the sun in a given time, and know the relative distance at which it is situated, we can at once determine its relative mass in regard to the sun. As a basis for this calculation, we have to commence with our knowledge of the distance through which any body will fall at the surface of the earth during the same time, and this we have already seen to be 16·1 feet per second. Now we know that the distance of the sun from the earth is about 23,300 times the radius of the earth, and therefore, at that distance the earth would only cause a body to fall through 16·1 feet divided by the square of this number. We can also determine from the distance and form of the earth's orbit how far the earth falls towards the sun in one second, and taking this distance into account, we find that the sun's mass must exceed that of the earth 324,000 times. In the same way we can determine the relative mass of every other planet; and this is made additionally easy in those cases where, like the earth, the planet is attended by a satellite, because from its motion

we can determine how far a body will fall upon the surface of the planet in a second of time, and then, from observations on the distance the planet in its motion in its orbit falls towards the sun, determine their relative masses. The actual weights are then easily obtained, because, since we know the weight of the earth, we have only to multiply this by the relative masses of the other bodies, and we obtain them at once. When we know the mass of a planet, and the radius or distance from the centre to the surface, we can then readily calculate the attraction of gravitation at its surface, and how far a body would fall there in one second of time. We thus find that 1 ton at the surface of the earth would weigh, if the weight were determined by a spring balance, about 27 tons at the surface of the sun, and $2\frac{1}{3}$ tons at the surface of Jupiter, while at the surface of the moon it would not be more than $3\frac{1}{3}$ cwts., and on the surface of some of the small asteroids, so light that a man could lift it with the greatest ease.

The enormous preponderance of the mass of the sun over that of all the planets singly and collectively is the real cause of the stability of the solar system, by preventing their mutual attractions from introducing such variation into their motions as would cause them either to come into collision or to change their orbits indefinitely.

98. *Perturbations of the Planets.*—If we suppose the planets to have their relative positions in space at any time determined strictly according to the laws of Kepler, we shall find that they do not exactly retain these calculated positions, when we come to observe them closely, over any considerable period of time, but are sometimes in advance and sometimes behind them. These changes are called *periodic variations.* To account for these variations, it is necessary to suppose that the elements of the orbit of the planet, or of the path in which it moves, are undergoing a slow and continuous change, so that the orbit is sometimes more

lliptical than at other times, and the plane of the lanet's motion also more or less inclined to the plane f the ecliptic. These changes are termed *secular ariations.* Both these variations are, however, recurrent fter the lapse of time, and are confined within very arrow limits, and do not extend to the alteration of he periodic time of revolution of any planet, because he axis major of the orbit of each planet, or the mean listance from the sun, remains constant; and upon this he periodic time depends.

Similar changes to those which the planetary orbits ndergo are visible in the motion of the moon and atellites of the various planets, and are, from the nature f the case, more rapid, and extend over shorter times. The moon, however, is too near to the earth to be much listurbed by the attraction of the other planets, but it is owerfully acted upon by the sun. This attraction varies vith its position in its orbit very much, because someimes it is nearer to the sun than at others, both in egard to its revolution round the earth, and to the osition of the earth in its orbit at aphelion and erihelion.

The time of revolution of the moon is greatest when n the latter position, and least in the former. The effect f this change in the time of revolution is called the *nnual equation.* The effect of the secular variations n the earth's orbit also gradually alters the orbit of the noon, and causes it to be larger as the eccentricity ncreases; and as we have already seen that this eccenricity is at present decreasing, there is also a slow lecrease in the moon's periodic time. This change is alled the *secular acceleration.* The attraction of the sun nd moon upon the earth also produces two remarkable listurbances, which are called the *precession of the quinoxes* and *nutation of the pole,* or axis of rotation. These really arise from the fact that the earth, rotating ipon its axis, is not a perfect sphere, but bulged out at he equator; and as the pole is inclined to the plane of

the ecliptic, the line of attraction of the sun is not towards the centre of the earth, because the mass at the equator, on the side nearest the sun, is more powerfully attracted than that farthest away, and this, coupled with a similar and greater attraction of the moon, and the rotation of the earth on its axis, produces a rotation of the pole round a central line, and a forward movement of the position in the orbit of the earth at which the equinoctial point is reached.

99. *Cause of Gravitation.*—The universal action of gravitation has caused many speculations as to what can be the real nature of the force, and the mechanical or other cause upon which it depends. The discovery of the existence of a medium in space, which is, when disturbed into vibrations, the mechanical cause of light and radiant heat, has suggested the possibility of a connection between this medium and the action of gravitation; but all the results of mathematical analysis reveal the fact that the transmission of gravitation is instantaneous, whatever may be its cause, while luminous vibrations, or, indeed, ethereal disturbances of any kind, are not so. The only theory which seems at any rate to satisfy the requirements of the case is that of Lesage, who supposes it to depend upon the existence of an infinite number of small atoms, or molecules, like those of a gas, only infinitely smaller, and which are in motion with enormous velocity in inter-stellar space, and which impinge upon all more dense matter with a velocity which causes pressure, like that of a gas upon the walls of the containing vessel. When two bodies are near to each other, they each shield the other from this battering action on the sides nearest each other, so that there is an excess of pressure on the outsides, which tends to force them together, and this action will be as the inverse square of the distance. The hypothesis, however, requires that all matter must be, to a large extent, inter-penetrated by these inter-stellar molecules, and a larger number pass through than are retarded, or else the attraction would not be as the

roduct of the mass. Ingenious as this theory un-oubtedly is, it can only be said to be a supposition until ur knowledge of the nature of the medium existing in pace, and inter-penetrating all matter, is much more dvanced than at the present time.

100. *Nebular Theory.*—In our examination of the olar system we have found that the orbits of the planets re nearly all circular in form, and that the planes in which they lie are almost coincident with the plane of he ecliptic; also, that the direction of revolution of he planets in their orbits and rotation on their axis is he same; and that the various satellites move round heir primaries also in this direction, with the exception f those of Uranus, and possibly Neptune. The times f revolution round the sun also increase in those planets which lie farthest from it, and the same law holds good in egard to the moons of those planets, which are attended y more than one; while the time of rotation on its axis, n the case of the sun, is less than the time of revolution of ny planet round the sun. The law of gravitation, which egulates the distances and motions of the planets in heir orbits, does not, however, account for these facts; ut they are so distinctive in their character that they ave long suggested to astronomers that they must have common cause, and thus, probably, a common origin, nd that the present condition of things may be the esult of the operation of the present known laws upon a ifferent condition of matter in the far past ages of the xistence of the universe.

We have already seen that there exists in space vast nasses of nebulous or gaseous matter in a state of in-andescence, and that in many of these singular nebulæ here appears every probability that they are undergoing slow process of condensation towards a centre, or entres; and a close inspection of these various degrees f condensation seems to reveal every stage, from that f the diffused luminous gas to that of a nebulous star. 'he hypothesis has, therefore, been suggested that at

some remote period of time the whole of the matter which now forms the solar system existed as a luminous or nebulous cloud, like those which are seen now in existence in distant parts of the universe, the dimensions of which extended far beyond the bounds of the orbit of Neptune; and that, from some cause or other, this nebulous mass was in a condition of slow rotation round its centre of gravity.

The unrequited radiation of the heat of this nebulous mass would, in the course of ages, undoubtedly result in a slow concentration of the mass towards its centre of gravity, and as the velocity of rotation of the molecules at the exterior of the mass would remain constant during the progress of the concentration, a time would undoubtedly come when, in consequence of the increased velocity of rotation, arising from the approximation of the molecules towards the centre of rotation, the force of gravity of a particle at the equator would be overcome by the centrifugal force generated by the velocity of rotation, and hence flat rings, or belts of nebulous matter, would be left behind, as the mass slowly concentrated. These belts would be formed in the plane of the equator of the nebulous globe, just as we see them at present exhibited in the Saturnian system. In these rings, or belts, the most rare portions, and those parts moving with the greatest velocity, would lie on the outside, and the more dense parts on the inside. If the cooling were perfectly uniform in every part, these various parts would ultimately tend to consolidate into a solid ring, providing their continuity was maintained; but if from any cause the continuity were broken, then the ring would break up either into detached masses, or concentrate from the two ends laterally into one mass, which, from the unequal velocity of its exterior and interior parts, would have a rotation on its axis, and that in the same direction as the rotation of the ring round the common centre.

A globe of nebulous matter would thus be formed rotating round the original nebulous mass, and separated

by an interval of space from its outer limit. This would form the substance of the future planet; and as this mass also slowly concentrated, we should have smaller rings thrown off, which would ultimately form the substance of satellites. In the case of Saturn, we have, probably, a condition of things similar to that which existed in the earlier history of all the outer members of the solar system; and the tendency to produce rings or moons would be greatest in the planets which were thrown off first from the nebulous mass, because the velocity of their particles would have the greatest differences, and the quantity of matter contained in them be also greatest. On this hypothesis the formation of the various planets was not simultaneous, but successive, the oldest being those farthest from the sun, and the satellites, in like manner, older than the planets as they appear at the present time. The time of rotation of the sun, or of any planet, must also be less than that of any body which circulates round them; and these facts, with few exceptions, agree with observation. If we could exactly deduce from the known rotation of the sun at present the relation between the radius-vector of its surface and the time of its rotation during the various stages of concentration which it underwent at the time when the planets were thrown off, the third law of Kepler would no longer be only a result of observation, but a legitimate deduction from the primordial laws of the universe. The sun itself is the still concentrating remains of the original nebulous mass, and whatever difficulties may be, and undoubtedly are, presented by the existence of comets and meteors, with retrograde motions and enormously inclined planes of orbit, the unity which this theory imparts to the composition and relations of the members of the solar system gives it the first claim to be considered as a highly probable event. More than this, the exact agreement between most of the observed phenomena and the requirements which are demanded by the mathematical and physical elements of

this theory, stamp it as one of the most remarkable results of human ingenuity, and unite the conditions which probably existed before the formation of the solar system began with those which are at present visible in the glowing suns which exist in space, and the nebulæ which stud the far-distant regions of immensity, at untold millions of leagues beyond the bounds of our stellar universe.

Part III.

CONDITIONS OF MATTER—MATTER IN RELATION TO FORCE.

CHAPTER I.

SOLIDS, INCLUDING GENERAL PRINCIPLES OF MECHANICS.

101. *States of Matter.*—Matter exists upon the surface of the earth—and, indeed, within the bounds of the physical universe—in one of three different states: viz., solid, liquid, or gaseous. The existence of these three different states of matter depends upon the relation between the molecular attractions and repulsions within the body, and for one and the same body these relations vary with the temperature; so that many substances, such as water, are known to exist under ordinary circumstances in all these different states. The pressure to which molecules are subjected has also a large share in the determination of the state which the matter will assume under different conditions. Whatever may be the nature of the sub-stratum of that which appeals to our senses as matter in any condition, whether it consists of hard ultimate atoms, or vortex motions of the substance of an ethereal medium, there is no doubt that matter is composed of discontinuous parts, separated from each other by an interval which is large when compared with the central nucleus, termed the *molecule*, and which is itself capable of further division into still smaller nuclei, termed *atoms*, with intervening spaces. The attraction of these atoms for each other seems quite independent of the absolute temperature of the matter, and increases

as the distance between the atoms grows less. This attraction, if not counteracted by any other force, would bring the atoms and molecules into absolute contact, and we should then have a manifestation of something which would probably be quite distinct from any of the states of matter at present known, and which we may term *the ultra-solid state,* where the matter would have no temperature whatever, and the motion of the molecules would entirely cease. In the state of solid matter, as we usually know it—so called in contradistinction to liquids and gases—we have this force of attraction balanced by the movement of the molecules amongst themselves, a movement which becomes greater or less as the absolute temperature rises or falls. In this state, however, the molecules do not travel from one part of the body to another, but possess a certain amount of adhesion, and retain fixity of position about the centres of oscillation. When the oscillation becomes so great that the fixity of position of the centres of oscillation is destroyed, then the matter changes its state, and becomes either liquid or gas. Under ordinary conditions, therefore, we may consider the nature of a solid body to be such that it has no motion of its parts which can be detected by the senses, and can therefore transmit the mechanical forces—such as pushes, pulls, pressures, or strains—to every part of the body, or to any other body in rigid connection with it.

102. *A Rigid Body.*—It is true that no solid body possesses this power to receive and transmit force without loss, because, as we have already seen, even those bodies which possess the property of solidity in the highest degree are flexible and elastic to a certain extent, and change their form more or less when subjected to pressure or strain, but in all the fundamental problems which are presented by the relations of solid bodies to force, these departures from the theoretical nature of a solid are ignored, and the body is assumed to possess absolute rigidity or fixity of parts when subjected to the action

of even an infinite force. The same assumption also applies to the part of the solid at which we suppose the force or forces acting upon it to operate. A force even of finite magnitude, if applied to a point, would inevitably fracture the body, because it is composed of discontinuous parts; but for the purposes of all statical and dynamical problems, we assume that the body can neither be fractured nor bent by the action of the force upon any point, however intense the force may be.

103. *Equilibrium.*—Whenever a solid body, which is free to move, is acted upon by two or more forces which do not move it, then the body is spoken of as in a state of *equilibrium*, and the forces are said to *balance* or *equilibrate* each other. The investigation of the conditions under which forces act upon solid matter, whether motion is produced or not, constitutes the science of *Stereo-Dynamics.* The department of mechanical philosophy, which treats of the conditions under which solid bodies remain at rest when under the action of force, is termed *Statics*, and investigates the laws of the balancing of forces. The department which treats of the movements of solids when under the action of forces which are not equilibrated, and of the laws which govern them, is called *Kinetics.*

104. *Conditions of Equilibrium.*—Whenever a solid body is under the action of forces which do not produce motion, the following conditions must be fulfilled. (1) The line of action along which the two or more forces or their resultant act must be one and the same; (2) the forces or their resultant must act along this common line in opposite directions; and (3) the forces, or the resultant of the forces, must be equal in magnitude and intensity, and they may be considered to act at any position along this common line of action. Upon this last condition depends the *transmissibility of force.*

105. *Action of Two Forces.*—If two forces act upon the same rigid body, in lines which form an angle with each other, so that they meet at a point, they may be repre-

sented by two lines which meet at a point whose different lengths shall respectively represent the magnitude of the two forces. If a parallelogram be constructed on these lines, then the diagonal drawn from the point at which they meet to the opposite corner will represent the magnitude and direction of a force which will balance the two forces, so that the rigid body, at the point, will be in equilibrium. Thus, in Fig. 14, if A C and B C, be two lines meeting at the point C, and representing two forces in magnitude and direction, and the parallelogram A D B C be completed, then the diagonal C D will represent in magnitude and direction another force, which will balance or equilibrate the two original forces. This is called the *parallelogram of forces.* If the forces A C and B C meeting at the point C were acting in the opposite direction, as shown in Fig. 15, then equilibrium would be produced by a force equal to C D, but acting in the direction of C E, so that the line C E drawn opposite to D C, and such that D C is equal to C E, will represent the force, and thus the parallelogram of forces will hold equally good. We have a familiar instance of the equilibrium of three forces acting at a point, and illustrating the parallelogram of forces, when we suspend two different weights over pulleys, and balance them by a third weight, as in Fig. 16, where we have two weights of 9 pounds and 6 pounds respectively balanced by one weight of 12 pounds, and the sides B D, C D, and the diagonal A D,

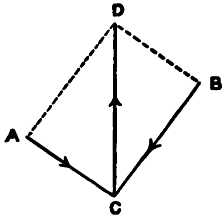

Fig. 14.—Parallelogram of Forces.

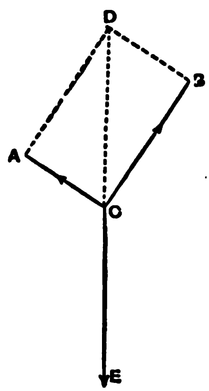

Fig. 15.—Parallelogram of Forces.

measure respectively 9, 6, and 12 units. The conditions of equilibrium of two forces, therefore, acting at a point, not in the same straight line, are equivalent to the action of three forces, one of which is the resultant of the two forces, and they may be represented by the three sides of a triangle taken one way round.

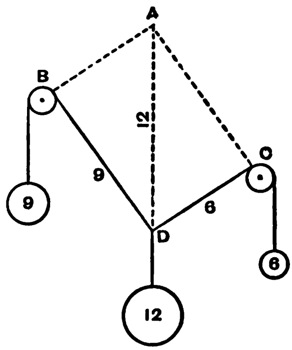

Fig. 16.—Parallelogram of Forces.

If the two forces acting upon a rigid body do not meet at a point, but are parallel to each other, they may be balanced by a parallel force acting upon the same body, but in an opposite direction. Thus in Fig. 17, let A B and D E be two parallel forces, acting upon the rigid body, or bar, A D, they will be balanced by an opposite force, C F, which is equal to the sum of AB and DE; or this force may be represented by the resistance of a fixed point beneath C, as in the fulcrum of a beam-scale, when the pressure upon the fulcrum will be equal to the sum of the weights in the two scale-pans.

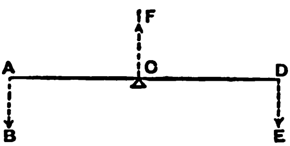

Fig. 17.—Equilibrium of Forces.

The conditions of equilibrium are easily seen where the forces A B and D E are equal to each other, but if AB is greater than DE, it will tend to produce rotation about the point C, in the direction A B. The same results will follow if the two forces remain the same, but the distances A C, D C, from the point C, at which they act, vary. In this case equilibrium will be established whenever the forces acting at the two points, A and D, multiplied into the length of the two distances, A C, D C, at which they

respectively act, are equal. The product of a force into a perpendicular, dropped from the fulcrum upon its line of action, is termed the *moment* of the force, and whenever, therefore, the moments of the forces on either side of the fulcrum are equal, equilibrium is established.

When two parallel forces act upon a rigid body, but in opposite directions, there is a tendency to produce rotation round a point somewhere between the point of application of these two forces. When two equal and parallel forces, acting in opposite directions, are applied to a rigid body, *a couple* is produced. The distance between their lines of action is called the *arm of the couple*, and the product of one of the two equal forces, by this arm, is called the *moment of the couple*. Equilibrium in a couple cannot be produced by the action of a single force, but it can be by the action of a couple of equal moment, moving in the opposite direction, provided that the two couples are either in the same, or else in parallel planes; and any number of couples in parallel planes, or in the same plane, are equivalent to one couple whose moment is equal to the algebraic sum of the moments of all the others.

106. *Action of Three Forces.*—If three forces act upon a point, and are not in the same plane, then the force which will counterbalance them, or produce equilibrium in a rigid body upon which they act, will not lie in the same plane as any two of them, but may be represented in magnitude and direction by the diagonal of a parallelepiped, of which three sides represent the three forces acting at a point in magnitude and direction. In Fig. 18, let A C, B C, and D C represent the three forces acting at the point C, then the diagonal of the parallele-

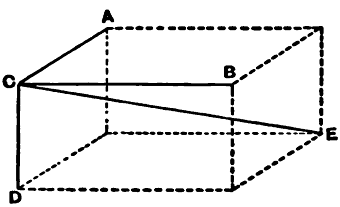

Fig. 18.—Parallelepiped of Forces.

piped C E will represent the resultant of these three forces in magnitude and direction. When the three forces acting at the point C are in the direction A C, B C, and D C, then the direction of the counterbalancing force will be in the direction C E; and when the three forces act in the direction C A, C B, C D, then the direction of the single force to produce equilibrium will be from E to C. This is called the *parallelepiped of forces.*

107. *General Resolution of Forces.*—In the same way, any number of forces acting upon a point in a rigid body may be resolved into one force acting at that point, and the conditions necessary for equilibrium will be fulfilled either by an equal force acting in an opposite way, along the same line of direction, or by the resolution of this counteracting force into any other number of forces, whose resultant shall be represented by this counteracting force in magnitude and direction. In cases where the forces applied to a rigid body do not meet at a point, but in parallel lines, they cannot always be represented or equilibrated by a single force, but they can be replaced by forces equal and parallel to them, and acting at any assumed point together with a number of couples. The forces acting at any assumed point can, however, by the resolution of forces, be replaced by a single force, which represents them in magnitude and direction, and the whole of the couples be reduced to a single couple, whose moment shall represent the sum of the moments of the original couples.

Thus any possible combination of forces applied to a rigid body may be reduced to a single force, acting along a definite line, and a couple which shall be perpendicular to this line. Such a combination of force and couple is termed a *wrench*, and the line of direction of the force the *axis of the wrench.*

108. *Force and Mass.*—The action of force upon matter varies with the quantity of matter which is acted upon. We have already seen (31) that the quantity of matter which is contained in any body is termed its mass,

and that on the surface of the earth the difference in the quantity, or mass, which any body contains may be considered to be estimated by its weight, which is really the amount of attraction which exists reciprocally between it and the mass of the earth, which is a constant standard. It will, however, be readily seen that if we had not the earth as a standard of reference, or were removed to some place where there was no attraction, then some other method for the determination of relative mass would have to be employed.

So long as we confined ourselves to matter of the same kind, such as iron or lead, this would be easy, because we know that equal volumes would, under the same conditions, contain equal masses; but when we came to compare different kinds of matter, such as iron with lead, then the case would be entirely different. The action of force upon matter, however, enables us to determine this readily, because two different substances always contain the same mass when the same amount of force produces in each the same velocity when acting upon them for the same length of time.

We may sum up the relation between force and mass as follows:—

(1) The velocities acquired by equal masses when acted upon by equal forces during equal times are equal also.

(2) The velocities acquired by different masses, under the action of equal forces, in equal times are inversely proportional to the masses.

(3) The velocities produced by forces of different magnitude, acting upon the same mass in equal times, are proportional to the forces.

(4) If different masses acquire in equal times equal velocities, the moving forces are proportional to the masses moved.

(5) The velocity generated by a constant force in the same mass is proportional to the time during which the force has acted.

(6) Under the action of a constant force, the space passed over varies as the square of the time during which the force acts.

109. *Falling Bodies.*—The fall of bodies to the earth, under the action of gravitation, affords one of the best illustrations of the action of a uniformly accelerating force. The resistance of the air causes bodies of different densities to fall with different velocities; but in a space where the air is all exhausted, and a vacuum produced, the time of descent, and the velocity acquired by all bodies in falling from the same height, is exactly the same. Under these circumstances, when a body is permitted to fall during one second of time in the latitude of London, it will pass over 16·1 feet, and will have acquired a velocity of 32·2 feet per second. The spaces passed over in successive seconds are as the odd numbers 1, 3, 5, 7, &c., and the spaces from the commencement are as the squares of the *times* in seconds, viz., 1, 2, 3, 4, &c., squared, or as the numbers 1, 4, 9, 16, &c.

The space passed through in any particular second is found by multiplying the constant 16·1 by the corresponding odd number, and the space from the commencement of falling by multiplying this constant 16·1 by the square of the number of seconds. The velocity at any point may be found by multiplying 32·2, the final velocity at the end of one second, by the number of seconds during which it has fallen.

When a body is projected upwards from the earth, the velocity with which it is moving is subject to a constant retarding action, which is exactly the reverse of the acceleration when the same body is falling. To find the length of time during which a body will rise when projected upwards with a given velocity in feet per second, we have only to divide this velocity by 32·2, and we obtain it at once; and the height, in feet, to which it will rise is found by dividing the square of the velocity by twice the acceleration of gravity in one second, which is $32{\cdot}2 \times 2 = 64{\cdot}4$.

110. *Projected Bodies.*—The action of gravitation is constant upon all bodies, whether they are projected vertically upwards or not. When the projection is vertically upwards, the velocity is retarded according to the law above indicated, until a point is reached when the motion is entirely arrested, and then, as in the case of an arrow or stone thrown upwards, they commence to descend, and fall to the earth with continually-augmented velocity. The time of fall is exactly the same as that occupied in rising, and the final velocity, as the body strikes the earth, exactly the same as the initial velocity with which it was projected upwards. If the body is projected horizontally, the action of gravitation deflects the body out of the straight line, and continually draws it downwards towards the earth, so that the path of the projectile becomes a curve. To find the nature of this curve, we have only to draw the horizontal line A B in Fig. 19, and mark out the successive points at which the moving body would arrive in successive seconds if gravity did not act, and from each of these points draw vertical lines, 1*a*, 2*a*, 3*a*, 4*a*, and equal to the space through which the body would have fallen up to the instant marked by the successive seconds, if it had fallen vertically under the action of gravity, without any horizontal motion, and then draw a curve through the successive points marked out by the junction of the vertical and horizontal lines, in the direction A, *a*, *a*, *a*, &c., to C, and this will give the path of the projectile. This is precisely that construction which is required to draw a parabola, and from

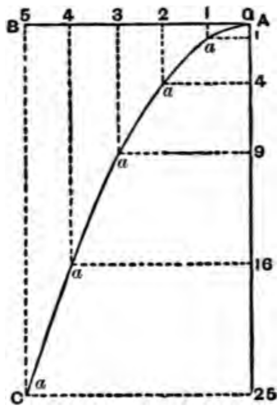

Fig. 19.—Trajectory.

this fact alone we can infer that the spaces passed through during the fall are proportional to the squares of the times of flight.

111. *Mechanical Work.*—Whenever a body is changed from a state of rest into one of motion, a certain amount of force is expended, and this is rendered latent by the performance of mechanical work, which can be measured by the amount of resistance which is overcome.

Whenever a body is raised from the ground, a certain amount of work is done against the action of gravitation, and this is a constant force which varies directly as the mass moved and the height to which it is raised, and the work done is also directly as this space. The work done by any living or inanimate agent is measured by the weight raised in pounds multiplied by the height in feet to which it is raised, and the *unit of work* is, therefore, called the *foot pound.* Thus, if 30 lbs. are raised 12 feet high against the force of gravitation, 360 units of work are performed. It will also be seen that although the body may remain in a state of rest after the act of raising it is accomplished, the work performed is not lost, because the body will be capable of, under suitable conditions, falling to the ground again, and in doing so can raise another weight, or, as in the case of a clock-weight, drive a train of wheels. In measuring the quantity of power which is expended in doing mechanical work, however, the element of time must also be introduced, because we can easily see how any agent which can raise, say, the 30 lbs. to a height of 12 feet in one second, must be much more powerful than one which can only accomplish the same work in, say, one minute. It is usual, therefore, in measuring the work which any agent can accomplish, to determine what weight in pounds can be raised one foot high when the whole power is expended during one minute of time. Thus we speak of *a horse-power* as represented by 33,000 lbs. raised one foot high in one minute of time. A steam-engine which could raise 330,000 lbs. of water one foot high, or 330 lbs.

1,000 feet high, when working during one minute, we should say indicated 10 horse-power. The weight lifted and the height to which it is lifted are convertible, since the same power which would raise 100 lbs. to a height of 10 feet would also raise 1,000 lbs. to a height of 1 foot, or 50 lbs. to a height of 20 feet. The work which is accumulated in any moving body is found by multiplying its weight in pounds by the square of its velocity in seconds, and dividing the product by twice the acceleration of gravity, which is $32 \cdot 2 \times 2 = 64 \cdot 4$.

The time during which work is performed, and the amount of work performed, are also convertible: that is to say, that any agent which works uniformly will perform twice the number of units of work during two minutes that are performed during one, and the same amount of energy which will perform, say, 100 units of work in ten minutes would, if entirely expended during one minute, perform 1,000 units of work. A weak agent can thus perform a large amount of work if more time is taken to do it, and a powerful agent continue to do a smaller amount of work during a longer period of time than if entirely expended in doing a larger amount in a shorter time.

112. *Simple Machines.*—It is often necessary to convert the work which is being actually performed by any agent into work of another form, either as regards mass, space, time, or velocity. Thus the work which a man can perform is often required to be expended in raising a weight which is much greater than he can lift at once, and which is incapable of being divided. The means by which this is accomplished is by the use of machines or mechanical contrivances, which enable him, or any other agent, to accumulate energy by working during a longer period of time or with a greater velocity, and expending this accumulation on the accomplishment of the desired object. No form of machine, however, can generate power, and the function of any machine, therefore, is *simply* confined to the conversion of one kind of work

into another. Nor can any machine, however constructed, entirely convert all the energy which sets it in motion into another form of work, because a certain portion of the moving force is always expended in overcoming the friction of the moving parts of the machine, and cannot be transmitted.

113. *Mechanical Powers.*—All machinery, including the most complicated forms, can be reduced to a few very simple machines, which have been named the mechanical powers, and which are usually considered to be six in number, although several of them are really only more complicated forms of the others. They are—(1) the lever; (2) the wheel and axle; (3) the pulley; (4) the inclined plane; (5) the screw; (6) the wedge. They might, as we shall afterwards see, be reduced to the lever, the pulley, and the inclined plane. In all the considerations connected with the investigation of the theoretical action of all machines, whether simple mechanical powers or not, it is usual to assume that the parts of the machines themselves have no weight, and move without friction, so that the whole of the power applied to the machine is entirely transmitted, and thus used in the performance of useful work: a condition of things which is, of course, absolutely impossible in practice.

114. *The Lever.*—The lever consists of a rigid bar, either straight or bent, and when the latter, the distances are to be measured along a straight line from the fulcrum to the points of application of the power and to the point of application of the weight to be lifted. It is usual to consider levers to be divided into three orders—(1) When the fulcrum, or point upon which the lever acts, is between the power and the weight; (2) when the weight is between the power and the fulcrum; (3) when the power is between the fulcrum and the weight. These three orders are illustrated in Figs. 20, 21, 22. In the first order of levers we have the conditions of equilibrium when the power multiplied into the distance at which it acts from the fulcrum is equal to the

weight multiplied into the distance at which it acts; and it will thus be easily seen that when the distance from the fulcrum to the power is greatest, and from the fulcrum to the weight least, the smallest power applied will lift the largest weight; but as the lever turns upon the fulcrum, the distance through which the power moves will be greater than that through which the weight moves. In this class of lever the mechanical advantage may be either in favour of the power or of the weight, whichever is farthest from the fulcrum obtaining it. A crowbar is a good example of this order of lever where the arms are unequal, and a beam-scale balance where the arms are equal, and thus any weight in one pan will, when equilibrium is established, be equal to any other placed in the opposite pan.

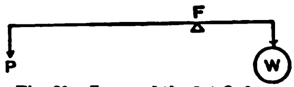

Fig. 20.—Lever of the 1st Order.

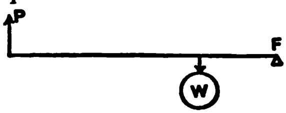

Fig. 21.—Lever of the 2nd Order.

In the second order of levers the weight is equal to the sum of the power and the pressure on the fulcrum, and the conditions of equilibrium are that the power multiplied into the distance at which it acts from the fulcrum is equal to the weight multiplied into the distance at which it acts. A wheel-barrow is a good example of this class of lever, and also an oar used in rowing a boat, where the man is the power, the water the fulcrum, and the boat the weight moved. In this class of lever the mechanical advantage is always in favour of the power. In the third order of lever the conditions of equilibrium are the same as in the other two—viz., the power multiplied into the distance from the fulcrum at which it acts is equal to the weight multiplied into the

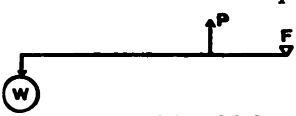

Fig. 22.—Lever of the 3rd Order.

distance at which it acts. In this order the mechanical advantage is always in favour of the weight, or the reverse of the second order, and the power, therefore, must always be greater than the weight, but it will always move through a smaller distance. A good example of this order of lever is the common lever safety-valve of a steam boiler or a pair of ordinary sugar-tongs. In any of the three forms of lever the mechanical advantage is always equal to the quotient of the longer arm, or distance from the fulcrum, divided by the shorter arm, and in favour of the power or weight, according as the one or the other acts at the longer or shorter distance.

115. *Wheel and Axle.*—The wheel and axle are really only an endless lever, the fulcrum of which is the centre of the axle, and the arms the distances which correspond to the radii of the wheel and the axle, and the conditions of equilibrium are such that the power and weight multiplied into the distance at which they respectively act from the common centre must be equal. This is seen at Fig. 23, where C A and C B correspond to the radii of the two circles, and if the weight acting at A and the distance A C are multiplied together, they will always equal the product of the weight acting at B, and at the distance B C when equilibrium is established. A C B is really a lever of the first order, with the fulcrum at C. When the power acts at the radius of the larger wheel, the mechanical advantage is in favour of the power, and the weight raised will be greater, but the speed of raising less. A good example of this is seen in an ordinary winch used for lifting or raising a bucket out of a well. When the power acts at the radius of the smaller wheel or axle, the mechanical advantage is in favour of the weight, but the speed is greater, and the power must therefore be greater than the weight. An example of this is seen in the driving-wheel of a locomotive, where the power is applied

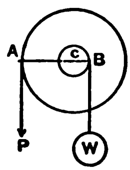

Fig. 23.—Wheel and Axle.

at the crank, and the weight moved at the circumference of the driving-wheel, and thus speed is gained at the expense of power.

116. *The Pulley* consists of a small wheel, which turns freely upon its axis, and which is usually grooved so as to permit a cord or rope to pass over it without slipping off the side. The pulley itself gives no mechanical advantage, except that it permits the direction of the force acting along the rope to be changed, which is often convenient, so that power may be applied more advantageously. Thus a man can lift a much larger weight by pulling downwards than lifting up, because the full weight of the body can be used as a counterweight.

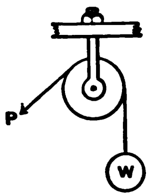

Fig 24.—Single Pulley.

At Fig. 24 we have a simple pulley with the cord passing over it, and the conditions of equilibrium are that the two weights shall be equal, because the pulley simply acts like a lever of the first order with equal arms. If, however, we arrange a system of two pulleys, of which one is fixed and the other movable, as in Fig. 25, and permit the cord to pass under one and over the other, it will be easily seen that since the cord is the same, the strain on every part of it must be the same, and the weight which is supported or carried by two strings will, therefore, carry a double weight to that exerted or suspended at the end of the single cord; but it is also obvious that if we move the power or weight suspended by the single cord through, say, one foot, the weight suspended by the double cord will only move through half that space, because only one foot of slack cord will pass over the fixed pulley, and will have to be divided between

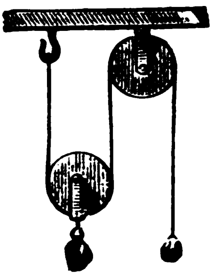

Fig. 25.—System of Two Pulleys.

;wo cords which suspend the movable pulley. The ht, therefore, although double the power, when iplied into the space through which ıs moved, will exactly equal the ır multiplied into the space through h it has moved, and thus equilibrium be established. In the same way ıay arrange a system of pulleys, such presented by Fig. 26, consisting of number of them, by means of which ın gain mechanical advantage in lift- a weight; but in all cases the dis- through which the weight can be d, when multiplied into the weight d, will always be equal to the weight ie power, or pressure applied at the : end of the cord, when multiplied the distance through which it has moved. Like the lever and the l and axle, therefore, the pulley ot create, but only distribute, power, nabling a small weight to balance ge one, by moving over a larger in the same time, or a larger ht to move a smaller over a larger in the same time.

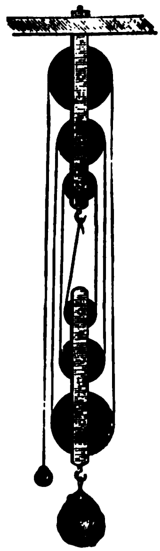

Fig. 26.—System of Six Pulleys.

17. *The Inclined Plane* is a means by which very great weights can be raised to any given height with the expenditure of far less power than could possibly raise the same weight vertically upwards. Fig. 27 is a section of such an inclined plane; and in moving any weight from A to B, it is quite clear that it have been raised through the vertical height B C;

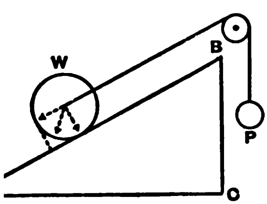

Fig. 27.—Inclined Plane.

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and the conditions of equilibrium are such, that if the vertical height B C, which is one side of the triangle, is half the length of the hypothenuse, or inclined plane A B, the power required to balance the weight moved up the inclined plane will only be half that weight. The reason of this is, that half of the weight is really supported on the plane, and in a state of equilibrium, and the remaining half, therefore, only requires to be moved. Since the weight of W is represented by the force of gravity, which acts perpendicularly downwards, this force is equivalent to two other forces, of which it is the resultant, one of which acts perpendicularly to the line A B, and is balanced by the resistance of the plane and the other at right angles to this force, in the direction of the tension of the string, and therefore alone requires to be balanced by the weight P. The mechanical advantage to be obtained by any inclined plane may therefore always be calculated by dividing the length of the plane by the vertical height to which it rises, and thus the weight raised, multiplied into the vertical height, will always be equal to the power required to balance the weight multiplied into the length of the plane. We have a good example of an inclined plane in the means usually employed to roll heavy casks into a dray by means of two planks of wood, extending from the ground upwards to the surface of the dray, or the winding of a road up the side of a hill, so as to make the distance, which is the length of the plane, longer, and thus ease the gradient.

118. *The Screw* is only another application of the inclined plane, for if we take a triangle of paper, or any other flexible material, as seen at A B C in Fig. 28, and wrap it round a cylinder, the edge of the inclined plane will form a spiral from the top to the bottom of the cylinder; and if this line be cut into the cylinder, it will form the grooves between the thread of the screw. When this cylinder is therefore turned round on its axis, it will either raise a nut, which is formed to correspond with it,

or, if the nut be fixed, raise or lower itself, according to the direction in which it is turned. Just as in the inclined plane—where we have seen that the longer the plane the greater the mechanical advantage—so in the screw: the finer the thread, or the longer the length of the spiral, the greater will be the mechanical advantage gained by its use, but the greater the number of revolutions will have to be made to raise the screw or nut through the same height. The length of one convolution of the screw represents the length of the plane, while the distance between any two threads corresponds to the height of the plane; and if we divide the former by the latter, we get the mechanical advantage which any screw will give. The screw is seldom used by itself, but generally with a lever to assist in turning the screw on its axis; and in this manner a man can exert a pressure, or lift a weight, far exceeding anything which he could possibly do by his unaided power, but he requires to act for a longer time in order to perform the work.

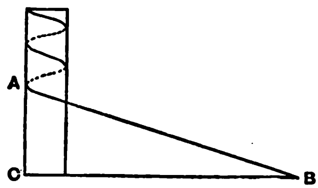


Fig. 28.—The Screw.

119. *The Wedge* is also only another form of the inclined plane. It is, in fact, two inclined planes with their bases together, and the double vertical height corresponds to the thickest part, or head, of the wedge.

The smaller the head of the wedge, in proportion to the length of the wedge, the greater the mechanical advantage gained, because we have virtually a longer plane in proportion to the vertical height. It is usually used to assist in the separation of masses of matter by being forced between them, and generally in combination with the mechanical advantage of storing up energy in the head of a hammer while in motion, and giving it up to the wedge in the impact of the blow. In this way it is possible to overcome resistances which would otherwise

require the use of far more complicated machinery. Many of our tools, such as those used in carpentry, and implements such as the plough, act upon the principle of the wedge.

120. *Complex Machines.*—However complicated any machine may be, it can always be reduced to the nature of one or other of the simple mechanical powers given above; and the principles which regulate the action of the most complex machines are exactly the same. No machine can be constructed which can create power, because if we multiply the weight employed to turn any machine into the distance or space through which it moves during a given time, the product will always equal the weight moved by the machine when multiplied into the distance moved over in the same time. This holds good whether we measure the pressures or weights in pounds, or tons, or ounces, or any common value, and thus perpetual motion is impossible. All machines, however, do not transmit all the energy which is communicated to them, as the waste is used in friction and overcoming the inertia of the machines themselves. If power were applied to a machine which did no work, it would be entirely expended in communicating motion to the machine, and the velocity of the machine would therefore be constantly accelerated till it would reach a maximum, and the motion of the point where the moving force was applied would be equal to the motion of the moving force itself. If, on the other hand, the resistance were continually increased, the machine would finally come to a stand when perfect equilibrium was established. Between these two points lies the greatest efficiency of the machine, or where the greatest amount of work can be done; and this has been found to be when the velocity of the point of application is about one-third of the maximum velocity above spoken of. This applies to all machines where motion or power is transmitted.

CHAPTER II.

HYDROSTATICS, INCLUDING THE GENERAL PROPERTIES OF LIQUIDS, AT REST AND IN MOTION.

121. *Molecular Structure of Liquids.*—We have already seen that when matter exists in the solid condition, the molecules, or ultimate parts of which it consists, possess a certain fixity of position with regard to the centres about which they oscillate, and do not, therefore, travel from one part of the structure to another, while they are held together by a sufficient force of cohesion to enable them to offer great resistance to any other matter which seeks to penetrate the mass. In liquids, on the other hand, the force of cohesion is very much reduced, and the fixity of position of the centres of oscillation entirely destroyed, so that the molecules are free to move under the action of force to any part of the containing vessel, and are displaced and inter-penetrated by the slightest force. As in the case of solids, the inter-molecular motions increase as the temperature of the liquid rises, and ultimately, when the temperature reaches a certain point, the bond of cohesion is entirely destroyed, and the molecules fly off into space and assume the gaseous condition. The temperature at which this effect occurs is called the *boiling point.* In all liquids, however, until the boiling point is reached, there is a certain amount of cohesion amongst the molecules, which causes them to cling together, or exhibit the property of *viscosity*, while they are free to assume any shape, and yet offer a very great resistance to compression.

122. *Compression of Liquids.*—For a long time it was supposed that liquids were absolutely incompressible, but with more accurate observation and instruments it has been found that this is not the case, but that all are more or less so, and that in all true liquids the decrease

in volume is directly proportional to the pressure. Whenever the pressure is removed, however great it may have been, the liquid always resumes its original volume, and liquids are therefore supposed to be perfectly elastic. The degree of compression in all liquids, even under the greatest pressure, is very small. In the case of water, the compression for one atmosphere, or 15 lbs. to the square inch, is only $\frac{1}{20,000}$th part of its volume.

123. *Pressure transmitted by Liquids.*—In consequence of the great incompressibility of liquids, and their perfect elasticity whenever they are subjected to pressure, they transmit it undiminished in every direction, and act with the same force on all equal surfaces. The consideration of the action of forces or pressures upon liquids, which forces produce a state of equilibrium or rest in the molecules of the liquid, constitutes the science of *hydrostatics*; while the investigation of the laws which regulate the motion or flow of liquids constitutes *hydro-dynamics*, or *hydro-kinetics*.

124. *Liquids under Gravitation.*—Gravity, or the attraction of the earth, acts upon liquids in the same way as upon solids, but the internal pressure produced within the liquid under this action varies at different points, and increases in intensity from the surface of the liquid downward. This will easily be seen if we consider any liquid contained in a vessel in a state of rest to be divided into horizontal layers of equal density, the lower of which always supports those which are above it. Under these conditions—(1) the pressure in every part of the same layer is equal; (2) the pressure in each layer is directly proportional to the depth or weight of liquid above it; (3) in different liquids at the same depth the pressure is proportional to the density. The pressure exerted by a column of water upon the bottom of any vessel or reservoir may be roughly considered to be half-a-pound weight for every square inch of surface and every foot in vertical height; and for any other liquid the pressure increases or diminishes in direct proportion *to the density* as compared with water.

We have already seen that the pressure exerted by liquids is equal in every direction, and consequently the downward pressure exerted by the different layers of any liquid produces an equal upward pressure, and this at any given point in the liquid is always equal to, and governed by, the same laws as the downward pressure. This upward pressure is called the *buoyancy* of liquids, and upon it depends the power of *flotation*.

125. *Liquids under Pressure.*—The pressure exerted by liquids is also quite independent of the form of the containing vessel, and from the perfect elasticity and mobility of the molecules of the liquid, the pressure exerted upon even the smallest part of the fluid is communicated over the whole area of the surface of the fluid in every direction. Upon this principle depends the action of the hydraulic press, where the pressure communicated to a small piston is communicated by the liquid over the area of a larger piston, with an equal force upon every part of the larger area; and thus a comparatively small pressure can be made to yield a much greater. This will be seen distinctly in Fig. 29, where the small piston exerts a force upon the surface of the liquid beneath it, which is communicated to the under surface of the large piston, and the pressure being the same on every square inch of the larger piston, we have a much larger power exerted. Thus, if the area of the larger piston exceeded the smaller by 1,000 times, we should have 1,000 times the pressure.

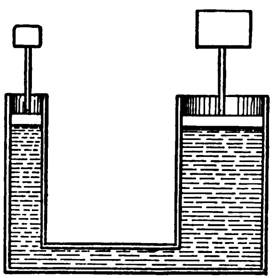


Fig. 29.—Hydraulic Press.

At first sight this may seem to contradict the principles laid down in the chapter on the action of machines, but when we remember that if the two cylinders containing the two pistons differ in area as 1 to 1,000, it will require

the small piston to move through 1,000 times the space that the large piston does; and, therefore, if we multiply the weight in both cases by the space moved over, the two results are equal, and there has been no creation of force, since the larger weight is lifted only $\frac{1}{1000}$th part of the space through which the smaller piston has moved.

126. *Equilibrium of Liquids.*—When under the action of gravitation, the surfaces of all liquids assume a horizontal position, because the surface of the liquid must everywhere be perpendicular to the resultant of the forces which act upon the molecules which compose it, and this at the free surface of a liquid will be in the direction of the plumb-line. The direction of the plumb-line varies with every position on the surface of the earth, and hence the free surface of the liquid will also vary, and form a curve, and not a plane, as we have already seen is the case with the surface of the ocean. For small surfaces, however, we may consider the surface of fluids when at rest to be a plane. Since the action of gravitation is practically constant within all small areas of the earth's surface, whenever liquids of the same kind are left to its action in vessels which communicate with each other, the surface in all will be at the same distance from the centre of the earth; or, in other words, liquids will always rise to the same level. Upon this principle depends the construction of the ordinary level for surveying purposes, and the supply of water from elevated reservoirs to the houses of towns.

When liquids which have not the power of diffusion, and possessing different densities in different vessels, are free to communicate with each other, they will, when equilibrium is established, not assume a level surface or equal height in the two vessels, but unequal heights of column. The height of the two columns will be in the inverse proportion of the density of the two liquids—that is to say, the denser liquid will require a higher column of the rarer liquid to balance it. When liquids of different densities, which do not diffuse into each other, such as

mercury, water, and oil, are mixed together, they will, when under the action of gravitation, arrange themselves according to their densities, the heaviest being at the bottom, and be separated from each other by distinct horizontal surfaces.

127. *Flotation of Solids.*—Whenever a solid body is immersed in a liquid, it is, like the volume of liquid which it has displaced, subject to the pressure of the surrounding molecules of the fluid. Now, we have seen that, although the pressure of liquids is the same in every part of a horizontal layer, it varies in the perpendicular layers directly as the depth of the liquid; and hence, since the bottom of the solid is deeper in the liquid than the top, the solid is pressed upwards by a pressure which is measured by the perpendicular depth of the solid, or the difference of the two columns of water which extend from the bottom and top of the solid to the surface of the liquid. The upward pressure is, therefore, equal to the weight of the volume of liquid displaced by the solid. All bodies, therefore, when immersed in liquids, lose a portion of their weight, which is dependent upon the volume occupied by the mass of matter and upon the density of the liquid. Whenever, therefore, a solid which has a less density than water is immersed in it, it will not only float upon the surface, but sink into it a portion of itself, which will displace a quantity of water exactly equal to its own weight. If the solid is denser than water, it will sink in the water, but beneath the surface of the water will be deprived of a part of its weight exactly equal to the weight of the water which its volume has displaced. It will thus be seen that even solids denser than water can be made to swim in it, if the solid is disposed in such a form that it will displace a sufficient quantity of water to outweigh itself. Upon this principle the hulls of ships can be made of iron, which is heavier than water, because from their hollow form they displace more water than their own weight.

128. *Specific Gravity.*—By taking advantage of the

property of liquids mentioned above, we have a very ready method of determining the relative density of different solids to water which is taken as the standard, and when determined in this way, this relative density is termed *specific gravity.* In order, therefore, to obtain the specific gravity of any body, we have only to determine its weight and the weight of an equal volume of water, and then divide the first weight by the second, and the quotient is the specific gravity of the body, when compared with water as unity. The determination may be made in many ways, which we cannot enter into here, but the principle involved in them all is stated above.

When the body whose specific gravity is sought is soluble in water, it is usual to determine its relative density with regard to some other liquid, such as oil or turpentine, whose specific gravity is known, and in which it is not soluble, and then multiply the result so obtained by the specific gravity of the liquid thus used, which will give the specific gravity of the solid relatively to water.

The specific gravity of liquids is obtained by weighing in each of them a known weight of any solid which is insoluble in each of them and in water, and the difference of each being noted, this weight represents the weight of an equal volume of water and of the given liquid; and it is only necessary to divide the weight of the displaced liquid by the weight of an equal quantity of water, and we obtain the specific gravity required. For the easy determination of the specific gravity of various liquids, such

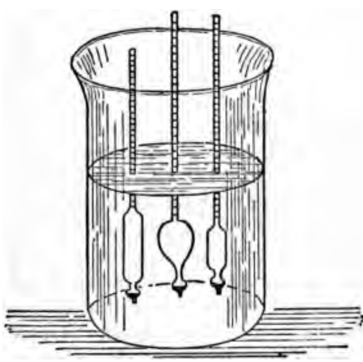


Fig. 30.—Hydrometers.

as oils, saccharine, or alcoholic solutions, it is usual to employ small instruments called *hydrometers*. These consist of a weighted bulb of glass and a long stem, which has previously been graduated according to various plans. This instrument is floated in the liquid the specific gravity of which is to be ascertained, and the position of the graduation from the zero point to the surface of the liquid read off, from which the specific gravity is easily determined, according to the method of graduation. The form and use of these instruments will be readily seen by reference to Fig. 30, where we have several forms of the hydrometer represented floating in the liquid whose density is to be determined.

129. *Capillary Attraction.*—Whenever solid bodies are brought into contact with liquids, at the point where the two touch each other we have a series of phenomena exhibited, which we term *capillary attraction.* The character of these phenomena depends upon the nature of the liquid used. Whenever a body, such as a glass rod, is placed in a liquid which wets it, the liquid becomes curved upwards against the side of the solid; and whenever the liquid is of such a nature that it will not wet the solid, then the liquid becomes depressed downward at the point of contact with the solid.

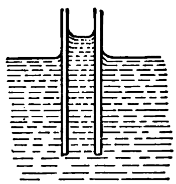


Fig. 31.—Capillary Attraction.

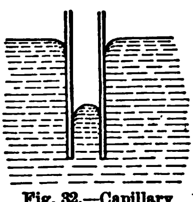


Fig. 32.—Capillary Attraction.

This effect is more distinctly seen when we employ tubes of glass of small diameter, for in the case where the liquid wets the glass we have the liquid rising up into the tube to a considerable height above the general level of the liquid. This will be seen at Fig. 31, where we have an illustration of the rise of water into a small tube. In the same way, the depression of mercury which does not wet the

glass is distinctly shown in Fig. 32, the level of the mercury within the tube being much below the general level of the surrounding mercury. The surface of the liquid within the tube is always concave when the liquid wets the glass, and convex when it does not. In consequence of this peculiarity, it is necessary to make allowance for this convexity when reading the height of a column of mercury in a barometer tube. The exact form of the curve assumed by the surface of the liquid depends upon the relation between the attraction of the solid for the liquid and the mutual attraction of the molecules of the liquid, which constitute its cohesive force. The ascent or descent of any liquid in tubes of small diameter are as the inverse ratio of the diameters of the tubes, and in the same liquid vary with the temperature, but are quite independent of the thickness of the tube. When two thin plates are immersed in any liquid, the liquid will rise, or be raised or depressed between the plates, according to the nature of the liquid, and for small spaces will be raised or depressed in the inverse ratio of the distance between them. The height or depression between the plates will be half that which would be produced in tubes whose diameter is equal to the distance between the plates.

In consequence of this action of capillarity, when bodies are floated on the surface of liquids, they are attracted or repelled from each other according to the nature and form of the body and of the liquid. It is also in consequence of this law of liquids that some insects are able to walk upon the surface of water, and also that oil or other inflammable liquids are drawn up into the wicks of lamps, and such substances as sand or sugar attract moisture up into their pores.

130. *Endosmose and Exosmose.*—Whenever two liquids of different densities are separated from each other by means of a thin porous diaphragm, or partition, currents of opposite directions are set up in them, and they tend to diffuse into each other. When the liquids

are of different densities, these currents are never equal, and in consequence one of the liquids tends to increase in volume, while the other on the opposite side of the partition decreases. The flow of the liquid towards the side which increases in volume is called *endosmose*, and in the opposite direction *exosmose*. If one of the liquids is enclosed in a bladder, or other organic membranous bag, which has a tube tied into the neck, so that when the liquid from the vessel in which the bladder is immersed diffuses into the bladder, the liquid rises up in the tube, and this rise becomes a measure of the energy of the diffusing action. Such an instrument is called an *endosmometer*. Upon this peculiar property of liquids depends the process of *Dialysis*. Professor Graham discovered that certain bodies when in solution pass through membranes with greater facility than others, and by placing the solutions of various substances within small vessels, which are termed *dialysers*, and which possess a bottom made of parchment paper, and floating them in pure water, the substances which are to be separated pass through the membrane into the pure water, where they can conveniently be examined. Upon this property also depends the means by which the food of plants and animals is absorbed out of the soil and the digestive tract into the circulating system, and thus enabled to nourish the organised structure.

131. *Flow of Liquids.*—If a vessel containing any liquid has an opening anywhere below the surface of the liquid, a quantity of the liquid will, under the action of gravity, escape out at the opening. The liquid, in escaping out of the side of the vessel through the opening, will be projected outwards, with a velocity depending on the depth of the opening from the surface of the vessel, the velocity increasing with the depth from the surface, because the pressure then is greater. When the liquid has left the orifice, it will fall under the action of gravity, in exactly the same manner as a solid body would do; and as each molecule of liquid is succeeded by another, so

that a continuous stream is formed, this stream takes the same form as the path of a projectile which is fired horizontally, and which we have already seen is a *parabola*.

If the vessel is so formed that the orifice at the bottom part of it opens upwards, then the liquid stream will form a jet, which is projected upwards. We have already seen that in closed channels water will always rise to its own level; and it would also do so in open jets, if it were not for the friction of the air and sides of the orifice, which retards its upward motion, and thus brings it to rest before the height of the column of water in the vessel out of which it rises is reached.

In ordinary fountains, the jets are usually connected with the reservoirs, which supply them by a series of tubes, which are often of great length, and the friction of the water in these tubes materially diminishes the velocity of flow, and thus the height to which the fountain can play. The quantity of water or any other liquid which can be discharged through a pipe is much less than can be discharged directly through an orifice of the same diameter made in the side of any containing vessel, on account of the great friction between the moving liquid and the sides of the tube. This is called the *hydraulic friction*. The friction increases very rapidly as the diameter of the tubes becomes smaller. It is also found that even when water or any other liquid passes through an orifice in a thin plate, the quantity of water which will flow out under a given pressure is diminished by the form which the liquid jet assumes, or the path which the molecules which compose the jet pursue in issuing through the orifice, and does not exceed $\frac{5}{8}$ths of what it would be if the motion of the molecules were unrestricted. When the liquid leaves the mouth of any orifice out of which it is escaping, it produces a *pressure of re-action*, which tends to move the vessel out of which the liquid is escaping in the opposite direction to the flow of the jet. This will be easily understood when we

remember that if the orifice is closed the liquid in the vessel will be in equilibrium, and the pressure equal on every part of it; but when the orifice is open, there will be an excess of pressure on the side of the vessel opposite to the opening equal to the pressure of the liquid over the area of the opening. A machine, called a re-action, or

Fig. 33.—Barker's Wheel.

Barker's wheel, has been constructed on this principle, where two jets are turned out on opposite sides of a tube, fixed to a vertical axis, and thus a couple is formed which causes rotation of the central axis. This will be best understood by reference to Fig. 33. Upon this principle are also constructed all the different forms of *turbines*, which are now very largely used as sources of motive power, especially where the volume of water is small and the height of the fall great.

The re-action of a liquid upon a solid in motion, which is of such a form as to create a current in one direction, is also taken advantage of in the construction of the *screw propeller*, which is now used in marine navigation in place of the old paddle-wheels. The propeller usually consists of an axis, upon which are fixed two or more segments of a screw, which are called the *blades* of the propeller. As the propeller is fixed into the stern of the vessel, its revolution in the water causes a re-action between the blades and the water, and this re-action forces the water backwards and the vessel forwards. The difference between the forward motion of the screw and the re-action which should be produced if the action of the screw upon the liquid were perfect, and without friction, is termed the *slip* of the screw.

CHAPTER III.

PNEUMATICS, INCLUDING THE GENERAL PROPERTIES OF GASES.

132. *Molecular Structure of Gases.*—We have already seen that in the solid state the force of cohesion amongst the molecules which form the matter is such that the molecules retain a certain fixity of position about their centres of oscillation, so that they are not free to move from place to place within the bounds of the solid. In the same way the molecules of any body when in the liquid condition have the force of cohesion so much reduced that this fixity of position of the molecules is destroyed, and they are free to move within the mass into any position when under the action of a disturbing force, but the cohesion is nevertheless not so much reduced that the tendency to remain together is destroyed,

even when not under pressure. In the gaseous state the force of cohesion of the molecules is entirely destroyed, and the molecules which compose the gas are in a constant state of repulsion, so that they possess the quality of perfect mobility, and are always, unless confined within a material boundary, tending to occupy a larger space. Within the volume of the gas the molecules are moving about in every direction with enormous and ever-varying velocities, and as a result they are incessantly coming into contact with each other. These molecular collisions occur many millions of times in every second. After every collision the path of the molecule is changed in direction, and the gas therefore exerts pressure in every direction on the interior of the containing vessel, and when free from any such restraining influence, would fly off into space if it were not for the action of gravitation. The gaseous condition is therefore a state which is dependent on the collisions of the molecules, and, as we shall afterwards see, if the number of molecules in any space is so reduced that the *free path* or space during which the molecules do not come into collision is so far increased that few collisions occur, then we have a new condition of matter manifesting itself, which does not exhibit gaseous properties, and which has been named by its discoverer, Professor Crookes, the *ultra-gaseous condition*.

As we have already seen in regard to liquids, the power to retain that condition by any mass of matter depends upon the absolute temperature, other conditions being the same; and in the same way the gaseous condition is also dependent on the temperature, since in the case of all gases, if the temperature is sufficiently reduced, the motion of the molecules, which is reduced with the fall of temperature, becomes too small to overcome the attraction of cohesion, and the body assumes the liquid condition.

133. *Gas under Pressure.*—We have already seen that in the case of solids the resistance to change of form or volume on the part of the matter is very great, and that

change, even under enormous pressures, only takes place within very narrow limits. In the same way liquids have been seen to resist the endeavour to change the volume with very great persistency, so much so that we can almost speak of them as incompressible, while their resistance to change of form, on account of the slight cohesion of the molecules, is very small. In gases, on the other hand, the resistance both to change of volume and form is very small indeed, as the molecular centres are long distances from each other, in proportion to their diameters, and the quantity of matter within the volume comparatively small, when considered in relation either to solids or liquids. The repulsion, or outward pressure of the molecules, always tends to make them fill any space, however large, within which they may be placed. In solids and liquids, the laws which regulate the variation in volume under changes of pressure are very complicated, and vary almost with each individual case, while those which regulate the relations of matter in the gaseous state are very simple, and are universally applicable to all permanent gases and their mixtures. In all permanent gases, the relation between *the volume which the gas occupies at the same temperature is inversely as the pressure.* This is to say, that if we have any space which contains any volume of gas, and we double the pressure upon that space, the gas will only occupy half the volume which it did at first, and if we halve the pressure, the volume assumed by the gas will be double that which it formerly occupied. If we increase the pressure four-fold, the volume assumed by the gas will be only one-quarter of its former volume, and if we diminish the pressure eight-fold, the volume occupied will be eight times as great. This law is termed the law of *Boyle* or *Mariotte*, from the two experimenters who discovered it independently. This law is found to hold good within all the limits where a mass of matter remains in the perfectly gaseous condition; and from the fact that under the alternate action of increased and diminished pressure all

gases immediately alter their volumes in accordance with this law, it is assumed that they are perfectly elastic.

134. *Gas under Change of Temperature.*—Like both solids and liquids, gas undergoes a change of volume when subjected to changes of temperature, but, unlike them, it is much greater for any given change of temperature, and quite constant in its action, whatever may be the nature of the gas, and whether it is purely of one kind or a mixture. In this respect gases differ entirely from both solids and liquids. The law which regulates the relation between temperature and volume in all gases may be stated thus—*The volume of a given mass of gas, when under a constant pressure, varies directly as the absolute temperature;* or, in other words, when under a constant pressure, the volume of a gas, within all limits where it continues to be a gas, varies by the same fraction of itself, when heated or cooled, by the same number of degrees of temperature. If the temperature is raised, the volume increases, and if it is lowered, it decreases. This law is called the *Law of Charles*, but also sometimes that of *Gay-Lussac* or *Dalton*. For air, which may be taken as the type of a permanent gas, the increase in volume from the freezing point at 32° Fahr., to the boiling point, at 212° Fahr., is from 1 to 1·3665, so that if we heat a given volume of air under a constant pressure from the freezing point to the boiling point, or through 180° Fahr., we shall increase the volume which it occupies by more than one-third of its original volume; and if we cool any permanent gas through 180° Fahr., we shall diminish its volume by more than one-third of the original volume. Exactly stated, the degree of expansion or contraction by being heated or cooled 1° Fahr. is $\frac{1}{490}$th part of the original volume of the gas.

135. *Weight of Gases.*—From the great fluidity and expansibility of matter when in the gaseous condition, it would almost seem as if gases would not be influenced by the action of the gravitating power of the earth in the same way as solids or liquids; but it has been conclusively

proved that all gases possess a definite weight, and are, therefore, acted upon by gravity just in the same way as the denser forms of matter. The weight really depends upon the mass of matter which occupies the volume which is selected to be operated upon, and, as we have seen, this volume depends both upon temperature and pressure, it is necessary to compare all gases with each other at a constant standard of temperature and pressure. In this country the standard temperature is the freezing point of water, which is 32° Fahr., and the standard pressure the average pressure of the atmosphere at the sea level, which is represented by the weight of a column of mercury. 30 inches in height, and corresponds to a pressure of 15 lbs. per square inch. Under these conditions, 100 cubic inches of air weigh 32·3 grains avoirdupois, while the same volume of hydrogen, which is the lightest known gas, weighs only 2·14 grains, and the same volume of carbonic acid 52·9 grains. This weight is obtained by taking a vessel of known capacity, say 100 cubic inches, and exhausting the air out of it by means of an air-pump, and then weighing it. It is then filled with either air or any other gas which is required, and weighed again. The increase in weight will correspond to the weight of that volume of gas.

136. *Pressure exerted by Gases.*—Every gas, from the very nature of its repulsive power amongst the molecules, exerts a pressure upon its own molecules, and this pressure is also exerted upon every part of the containing vessel, in the same way as we have already seen to be the case with liquids. On account of the much less density of gases, as compared with liquids, however, in small confined spaces, we may consider the force of gravity to be inoperative, and the pressure to be the same in every part of the containing vessel. In the case of liquids, we have already seen that the pressure on the bottom and sides of any containing vessel increases rapidly as the depth of the liquid, or, what is the same thing, the height of the column of liquid increases, because if we consider

the column to be divided into horizontal layers, those beneath have to support those which are above. The pressure in the same layer is the same in every direction, but it varies in every layer. In the same way, when we have to consider large volumes of gas, such as the atmosphere which surrounds the earth, we are obliged to take into account the fact that in a gaseous, as in a liquid column, the lower layers have to support the upper, and the pressure is not the same in any part of the column, when taken upwards or downwards. The pressure at the bottom of the column of gas increases with the height of the column, and on the same area is quite independent of the form of the containing vessel.

137. *The Atmosphere* consists of a vast ocean of gas, which surrounds the earth on every side, and which practically consists of two chemical elements, which are called oxygen and nitrogen. The oxygen is a gas which supports life and combustion, and the function of the nitrogen, so far as life is concerned, seems to be to dilute the oxygen, and prevent its action from being too energetic. By weight, the air consists of oxygen, 23 parts, and nitrogen 77 parts, and by volume, 20·8 parts to 79·2 parts. The action of gravitation keeps the atmosphere round the earth in the same way that the waters of the ocean are kept in the bed of the ocean, and as a consequence, the pressure of the air decreases as we ascend upwards from the surface of the earth. At the outer limit of the atmosphere, however far upwards it may extend, the expansive force of the molecules is balanced by the attraction of gravitation, so that it does not extend to an indefinite distance from the surface of the earth. At the surface of the earth the pressure of the air is very great when taken over any extended area, as may be easily proved by taking any vessel, such as a glass jar with an air-tight membrane stretched over the neck of the jar, and exhausting the air out of it. Long before all the air is removed, the difference in pressure

between the outside and inside will bend in the membrane, and finally rupture it with a loud report.

138. *The Barometer.*—This is an instrument which, in its various forms, enables the pressure of the air to be measured. In its simplest form, it consists of a long stout glass tube, about 40 inches in length, and closed at one end, as at Fig. 34. This tube is inverted and filled with mercury, and then, by stopping the end of the tube with the thumb or other means, it can be again inverted with the open end down into an open vessel containing mercury. When this is done, it will be found that the column of mercury falls in the tube for a certain distance, and then remains stationary, leaving an empty space between the top of the closed tube and the surface of the mercury in the tube. This space is termed a *Torricellian vacuum*, and is one of the most perfect which can be obtained. This column of mercury in the tube varies in height at different times, and also always decreases in height when the apparatus is carried upwards from the surface of the earth, as in the ascent of a balloon or the climbing of a mountain. This arises from the fact that as there is a vacuum in the top end of the tube, the column of mercury is balanced by a column of air of equal diameter extending to the limit of the atmosphere, and of course, as we ascend this equiponderant column becomes less, and therefore the mercury falls; while, if we descend, the equiponderant column becomes higher, and the mercury rises. At the sea-level, when the temperature is about the freezing point, the height of

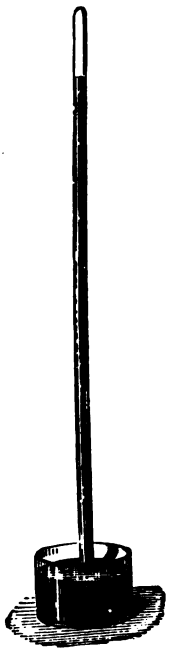


Fig. 34.—Barometer.

the mercury column is about 30 inches, and the weight of this column becomes the measure of the pressure or weight exerted by the equiponderant column of air. A column of mercury of this height, and having an area of one square inch, weighs about 15 lbs., and hence we say the pressure of the atmosphere is about 15 lbs. to the square inch on the whole surface of every object upon which it presses. If a liquid less dense than mercury is employed, the height at which the column of liquid within the tube will stand is proportionally increased. Thus water is about $13\frac{1}{2}$ times lighter than mercury, and if we employ it instead of mercury, the tube will require to be much longer. A column of mercury of 30 inches will be about equal to a column of water 32 feet high. Such a column, when employed as a water barometer, is much more sensitive, since it rises or falls a foot for every inch of variation in the mercury barometer, but its great length renders it very cumbersome, and it is only seldom used. The total pressure of the air upon objects at the surface of the earth is very great. Thus, the weight pressing upon the surface of the body of an ordinary-sized man is in the aggregate from twelve to fourteen tons, but as the air penetrates the body, there is an equal pressure acting outward, which prevents this from being felt. The height of the column of air is continually varying from different causes, and hence the rise and fall of the column of mercury in the tube become the measure of the variation in pressure of the atmosphere; and thus, if the tube is graduated into inches or other divisions, the rise and fall of the column can be registered. The variation in pressure of the air is usually accompanied by meteorological changes, and hence the rise or fall of the barometer, when taken in conjunction with the direction of the wind and the changes in temperature, becomes a trustworthy guide for changes in the weather. For very small variations in atmospheric pressure, the rise or fall in the mercury column is so small that it can only be detected by very close observation, and hence in

practice, especially where great accuracy is not required, various means are employed to increase the magnitude of the motion. One of the most common is to turn the end of the barometer tube upwards at the bottom, so that the cistern or supply of mercury for the column to rise or fall upon is of about the same diameter as the tube, and upon the surface of the mercury a small float is placed, which carries a cord over a wheel, that works a pointer, like the hand of a clock. The clock-face can be made any required size, so that a very small angular deviation will give a very large division on the circumference of the dial. Such an instrument as this is called a *wheel barometer*. Since the barometer rises and falls with increase or decrease in the elevation above the surface of the earth, the barometer can be used for determining the height of mountains and the depth of mines. A mercury column is, however, not easily carried, and hence a different instrument has been constructed, which is far more portable, and which is called the *aneroid* barometer. It consists of a vacuous cylinder, or other shaped cavity, the walls of which are made of very thin elastic metal, and as the pressure of the outside air acts upon the walls of this cavity, they are forced in or expand outward as the pressure increases or diminishes, and a suitable means is employed to enable this motion of the walls of the cavity to be communicated

Fig. 35.—Aneroid Barometer.

to a hand like that of a clock or of the wheel barometer, and thus the variation is recorded. The scale of this instrument is corrected with the rise and fall of the mercury column under similar circumstances, and thus the aneroid is practically available for every purpose to which we can apply the ordinary barometer. Fig. 35 is an illustration of an aneroid barometer, where the vacuous vessel is made in the form of a hollow circular ribbon, the ends of which are connected with the recording mechanism.

It is usual for the small aneroid barometers to be graduated for the measurements of height or depth as well as for meteorological purposes, and as this scale can be set to zero at any time, the height or depth above any given level can be read off at once as the journey is progressing.

139. *The Air-Pump.*—In consequence of the great elasticity of the air, it can be pumped out of any space by the action of suitable apparatus, and a partial vacuum produced in the containing vessel. We say partial, because no means at our command enables us to produce an absolutely perfect vacuum, where no trace whatever of air or other gaseous body is found. When a vacuum is thus produced, the surrounding air exerts a pressure of about 15 lbs. per square inch upon the whole area of this vessel, which is not the case under ordinary circumstances, because the pressure of the air is exerted inside as well as outside of any vessel to which it has access, and the two pressures balance each other.

Within the vacuous vessel, any two bodies which differ in density, such as a feather and a sovereign or ball of lead, fall to the ground with equal velocity, because they are unimpeded by the friction of the air, which acts differently upon them. The sound of a bell rung within the vacuum is unheard, because there is no air to communicate the sound of the vibration to the ear. A closed bladder with the smallest quantity of air remaining within it will, in this vacuum, expand as if it were full of air, and a bird or any small animal

which may be introduced will die, and a candle be extinguished.

The production of a vacuum within the cylinder of a steam-engine, by the condensation of the steam in the condenser, increases the pressure on the opposite side of the piston just in proportion to the perfection of the vacuum up to 15 lbs. per square inch, and thus increases the efficiency of the engine and the economy of its working. In actual practice, even under the most favourable conditions, the vacuum in the condenser seldom exceeds 12 to 13 lbs. per square inch. The action of all lifting pumps depends upon the fact that the removal of the liquid out of the barrel of the pump by the bucket produces a partial vacuum, and the pressure of the air upon the surface of the water in the well or vessel out of which it is being pumped forces up a fresh portion of liquid to the under surface of the bucket, ready for the return stroke. This is the reason why a single pump will never draw water when placed above a certain height above the surface of the water in the well or river out of which it is to be drawn. Upon this principle also depends the action of the *syphon*, which consists of a bent ∩-shaped tube with unequal legs, and which, when the shorter leg is placed in any vessel containing liquid, will draw off the liquid over the side of the vessel whenever a vacuum is produced in the longer tube. The liquid will rise by the atmospheric pressure over the bend into the longer leg, and as it is continually falling out at the bottom of the longer tube, it also continuously produces a vacuum, which raises a fresh portion of liquid over the edge of the vessel.

140. *Mixture of Gases.*—We have already seen that when liquids of different densities, which have no chemical action upon each other, are mixed together, they only assume a condition of equilibrium when they have arranged themselves in the order of their densities, decreasing from the bottom of the vessel upwards. On account of the perfect mobility of the molecules of all

permanent gases, and their great elasticity, whenever they are mixed together in any proportion, no separation takes place, but equilibrium is established by the mixture of the various gases, in such a manner that each part of the total volume contains equal parts of each of the gases composing the mixture. In addition to this, the total pressure which is exerted upon the walls of the vessel which contains the mixture is the exact sum of the individual pressures which each of the component gases would have exerted if they had separately occupied the vessel.

141. *Transfusion of Gases.*—If two gases which possess different densities, such as oxygen and hydrogen, are placed in two separate vessels which are connected by a small tube, it will be found, after a time, that they have become entirely mixed, and an equal portion of each gas will be found in each vessel. When this mixture has once occurred, the gases never separate again in the order of their specific gravities. Gases transfuse into each other according to a law of velocity which varies as the inverse ratio of the square roots of their respective densities, so that a lighter gas will penetrate into a heavier gas with greater velocity than the heavier penetrates into the lighter. In consequence of this, if we surround a porous vessel containing a gas, such as hydrogen, by an atmosphere of a denser gas, such as air, the hydrogen will pass through the porous walls of the vessel with greater velocity than the air can pass in, and the pressure will fall within the porous vessel, and the partial vacuum produced can be made to raise a column of liquid. The height to which this column rises becomes a measure of the energy with which the gases transfuse. The gases, indeed, act like a vacuum to each other, and it has been found, in the case of hydrogen, that it penetrates through a thin porous membrane, or septum, into a vacuum with the same absolute velocity that it does into air. Upon this diffusibility of gases into each other depends the constant composition of the atmosphere,

which is identically the same whether taken at the surface of the earth or the top of the mountains—amidst the crowded cities or in the sandy desert.

142. *Absorption of Gases.*—Not only do gases possess the power to interpenetrate each other, but also to enter the pores or molecular interstices of both liquid and solid bodies. Different substances, however, differ very widely in this respect, and also in the quantities of gas which they can absorb, even under the same conditions of temperature and pressure. At the ordinary pressure and temperature of the air, water will absorb as much as 430 times its own volume of ammonia gas, while it can only absorb the $\frac{25}{1000}$th of its volume of nitrogen and the $\frac{46}{1000}$th of its volume of oxygen. Also the volume of gas which a given liquid will absorb is proportioned to the pressure on the surface of the liquid, so that with a double pressure a double volume of gas is absorbed. Moreover it seems that the quantity of another gas which a liquid can absorb is independent of the nature and quantity of the gas which it already holds in solution.

Solids also vary much in their power to absorb gases; and a very notable instance occurs in the case of charcoal when made from logwood, which can absorb as much as 111 times its own volume of ammonia. Even metals possess this power; and when platinum is in the spongy condition, and a jet of hydrogen is directed into it, the condensation within the pores of the platinum is sufficient to raise it to a red heat, which ignites the hydrogen if oxygen is also present.

CHAPTER IV.

ACOUSTICS, INCLUDING THE NATURE AND LAWS OF SOUND.

143. *Propagation of Sound.*—We have already seen when a bell is sounded within the exhausted receiver of an air-pump, that when due precautions are observed to prevent the propagation of the sound through the metal of the pump, no sound whatever can be detected by the ear. From this experiment it is quite evident that the air forms the medium through which the sound is propagated; and from the fact that when a bell is sounded at a distance it takes a certain period of time to reach the observer, it is also certain that it is not propagated instantly. The velocity of sound, indeed, in any gas varies with the nature of the gas, being greatest in dense gases and slowest in rare gases. In air, at the temperature of freezing water, 32° Fahr., and the density represented by the mercury column in the barometer standing at 30 inches in height, the velocity of sound is about 1,093 feet per second; but there is reason to believe that a very loud sound, such as that produced by the firing of a cannon, is propagated more rapidly than a weak one. The velocity, as we shall afterwards see, increases with the increase of temperature, and also with the density of the body through which the sound is propagated. In water, sound travels 4,700 feet per second, or more than four times as fast as in air, and through a rod of wood eighteen times as fast as in air, or with a velocity of very nearly 20,000 feet per second.

144. *Waves.*—When an elastic body is compressed or extended in any part, the whole of the molecules which compose it are not affected at once, but the motion communicated at the point of application is transmitted from molecule to molecule by a series of actions which but very slightly disturb each molecule out of its condition of

equilibrium, and yet transmit the whole of the motion forward.

This action will be more easily understood by reference to Fig. 36. If a number of hard ivory balls are suspended by strings, so arranged that the balls each just touch the other, and an impulse be given to No. 1 in the direction shown by the arrow — which may be accomplished by drawing No. 1 away from No. 2, and permitting it to fall against No. 2 under the action of gravity—then No. 1 will give up its motion to 2, and 2 to 3, until the last ball, 6, is reached, and as there is no other ball to communicate motion to, this ball will fly off, as represented in the diagram. The energy of the first ball is, therefore, communicated to the last without any visible motion of the intervening balls. The cause of this arises from the fact that when the first ball strikes the second, the molecules composing it are compressed together, and their reaction in returning to a condition of equilibrium communicates the motion of compression and after expansion onwards, and thus the last ball, being unable to re-act upon any other, is itself moved forward bodily. If we take an elastic cord and stretch it, by attaching one end to a hook or other convenient attachment, and hold the other end in the hand, and then give the cord an up-and-down movement, we shall see the motion communicated along the cord in a wave-like form to the attached end,

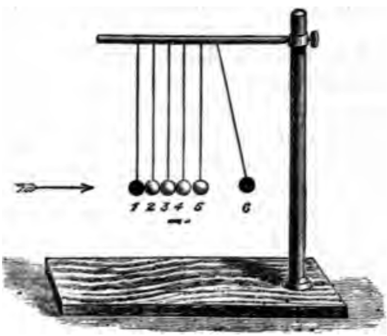


Fig. 36.—Transmission of Force.

and then, by a re-action, returned back again along the cord to the hand. If a series of beads be strung on to the string, they will move to and fro with the undulations of the cord, but will have no motion of progression along it. If the surface of a liquid is disturbed by dropping a stone or other solid into it, the equilibrium of the molecules which compose the liquid, such as water or mercury, is disturbed, and an area of depression produced, which is immediately followed by the production of a ridge of elevation around the area of depression, and this disturbance is propagated by a series of alternate depressions and elevations, which constitute concentric waves, which move outwards. The circular line marked out by any of the circular ridges is called a *wave front;* and if any solid particle be floating on the surface of the liquid, it will be found that, although it falls and rises with the depression and elevation of the surface of the liquid, it has no motion onwards. The motion is propagated through the molecules of the liquid by a series of impulses, which cause the molecules to swing to and fro without any great displacement of the centres of motion. In the case of an impulse communicated to the molecules of a gas, it cannot be transmitted in the same way as in a solid or liquid, because there is not the same molecular tenacity, and the distances between the molecular centres are greater. Gases are, however, capable of assuming a wave motion, by means of which an impulse communicated to one part of the gaseous volume can be propagated through it. In the case of a cord or of the free surface of a liquid, the undulations which transmit the impulse are at right angles to the direction of the propagation of the wave motion, but in the case of gases the motion is communicated by a series of alternate condensations and rarefactions of the gas, which take place in the direction of the propagation of the impulse. In the case of impulses communicated to the interior of solids and liquids, when the free surface is far removed from the point of application of the impulse, a similar method of wave propagation

also occurs. When sound-waves are produced in air, their effect is to increase the temperature in those parts of the wave where compression is produced, and lower it where there is expansion. The condensed part of the wave, therefore, becomes more elastic, and the expanded part less elastic, so that they both change their condition again with greater rapidity than they would have done if the temperature had in both cases remained

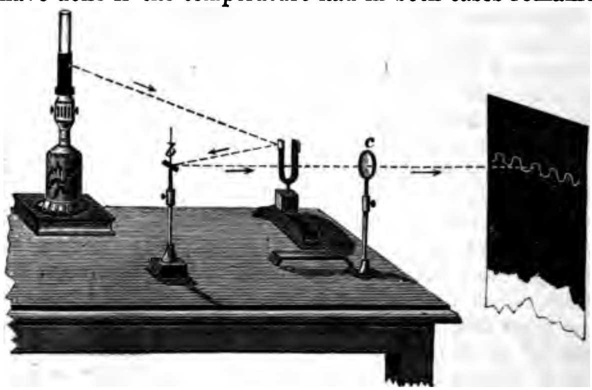


Fig. 37.—Vibrating Fork.

the same. Thus, while the average temperature of the air remains the same, the velocity of the sound-wave is increased.

145. *Cause of Sound.*—The cause of sound is undoubtedly the result produced on the air by the vibration of the sounding body, for if we surround a bell with a number of suspended light balls, which just touch the edge of the bell, they are thrown into a state of violent rhythmic agitation whenever the bell is struck so as to produce a sound. We can also render the motion of a sounding body visible to the eye in a very distinct and striking manner if we permit a ray of light, as in Fig. 37, *to fall* upon a small mirror fixed on one of the arms of a

sounding tuning-fork, and then, by reflection at *b*, pass it through the lens *c* on to a dark screen. Here the undulation of the ray of light caused by the vibration of the arm of the fork forms an undulating luminous line. By combining the motions of two tuning-forks upon the ray of light, by successive reflection from the two vibrating surfaces, some beautiful forms of undulation can be obtained.

146. *Nature of Sonorous Undulations.*—The last illustration shows the difference in the nature of an undulatory motion and ordinary motion, such as that of a cannon-ball. In the case of ordinary motion the whole body moves forward bodily, but in the case of undulatory motion the molecules of the body only move backward and forward about a mean place of motion; and in the case of a sound-wave the condensation and rarefaction produced by the vibrating body in the air moves onward, but the molecules of the air itself have only a slight motion of displacement backward and forward. We can form the best conception of the nature of a sound-wave which is propagated from a sounding body in every direction by imagining the sudden expansion of a small mass of solid matter within a volume of air whose molecules are at rest. The air all round the expanding solid will be thrust away from it in the form of a spherical shell, and driven into the space occupied by the surrounding air before it can be set in motion, and, consequently, there will be a sphere of condensed air momentarily round the expanding body. This condition can only be maintained for a very short interval of time, because the re-action of the air upon the expanding shell of condensation will drive the molecules back again, and farther back than their original position, so that there will be produced a corresponding shell of greater rarefaction than the air. This rarefaction will produce a larger area of condensation outside itself, and thus the effect will be the propagation outward of one chief shell of compression or condensation, followed by one chief wave of rarefaction of much less

intensity, both of which grow less and less intense as they are farther removed from the expanding centre, and act upon a larger and larger shell of air. If we were to cut through such a sphere of condensing and rarefying air, we should have, if we could render the effects visible, an effect produced something like that given in Fig. 38, where the two conditions follow each other in continually widening circles, which are propagated outwards to the limits of the air or other vibrating medium. This being the case, it will easily be seen that the intensity of sound, at any distance from the centre of sound, is related to the distance as the inverse square of that distance, because the areas of the successive spheres are related to each other as the square of their radii, and the sound decreases in intensity in proportion to the area over which it is spread.

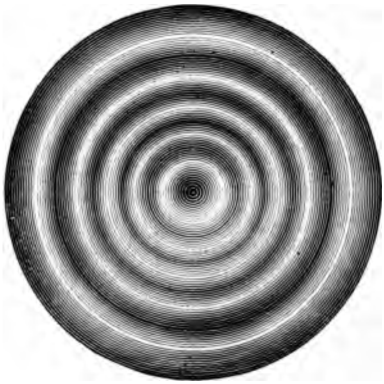


Fig. 38.—Sound Waves.

The whole of a condensed and expanded wave forms what is termed an *undulation*, while the space which the sound travels over during the time one undulation, or alternate expansion and contraction of the vibrating medium, is being performed, is termed the *length of the undulation*. The degree of departure from the state of rest of the molecules of the vibrating medium, measured from the two maximum distances on either side of the point of rest, is termed the *amplitude of the undulation*. We have already seen that in a vibrating pendulum the *time* of vibration is quite independent of the size of the

arc through which it vibrates, and in the same way the time of vibration of the molecules of elastic bodies is quite independent of the extent of motion or amplitude of the vibration; and thus we may have two sizes of waves, in both of which the wave length and velocity of propagation may be the same, although the extent of the vibration of the individual molecules may be very different in the two. The length of the wave in sounding media determines the note or distinctive character of the sound, while the amplitude of the vibration determines the intensity of the sound. Hence we may have two different notes sounding with the same degree of intensity, or the same note with different degrees of intensity.

147. *Causes influencing the Intensity of Sound.*—We have already seen that sounds decrease in intensity as we recede from the sounding body, and follow the law of the inverse square of the distance. The intensity of the sound is also much influenced by the nature of the medium through which the sound is propagated. Under the receiver of an air-pump, the intensity of a sounding bell decreases as the rarefaction of the air proceeds, and ceases altogether when a vacuum is produced. In the same way, the same bell sounded in the dense air of a valley is much louder than when sounded on the top of a mountain, and less at the same pressure in hydrogen gas than in air, because the density of hydrogen is only about $\frac{1}{14}$th the density of air. In the open air, sound is always more intense in calm than in windy weather, and when wind is blowing, more intense in the direction of the wind than in the contrary direction. The intensity of sound is also much increased by the proximity of other sounding bodies, because these are thrown into responsive vibration, and tend to increase the amplitude of the sound-wave. Hence the use of sound-boards or boxes in connection with musical instruments.

148. *Musical Sound and Noise.*—When a sudden impulse is communicated to the air or any other vibrating medium, a sound is produced which has no perceptible

wave-length, and this, when it reaches the ear, is termed a *noise*. A noise may also be produced by a succession of sounds or wave-lengths, which have no definite relation to each other so far as time is concerned. If, however, the impulses which produce the sound occur at regular intervals, then the ear recognises the existence of a definite wave-length, because the molecules of the vibrating medium are definitely rhythmic, and produce a pleasing sensation; and this we call a *musical note*. It is found that a certain number of impulses must be given in a certain time before the ear can be sensible of musical sound, and that when these impulses exceed a given number in a given time, then the ear again loses the power to appreciate them. The commencement of musical sounds begins when the number of vibrations reaches 32 in one second, and continues until the number reaches 8,132 in one second. The longer the interval between the impulses, the longer the wave-length, and this corresponds to the deepest bass notes, while the shorter intervals indicate shorter wave-lengths, and these correspond to the treble. The deepest bass, with 32 vibrations in one second, has a wave-length of 32 feet, while the highest treble, with 8,132 vibrations per second, has a wave-length of only $1\frac{1}{8}$ inches. The ear in different individuals undoubtedly possesses a different power in the discrimination of these wave-lengths, so that one ear may be capable of receiving sounds which are inaudible to the other; but the wave-lengths given above mark the average range of sensibility of the human ear.

149. *Determination of Number of Vibrations and Wave-length.*—The absolute number of vibrations of the sonorous body which corresponds with any definite musical note can be determined by means of an apparatus, called after its inventor, Savart's Machine. Fig. 39 is an illustration of this machine, where a large wheel A, when the crank M is turned, communicates motion by means of a band D to the toothed wheel B. Into the teeth of this wheel a

card E is fitted so that it is attached to the framework of the machine, and free to vibrate every time it is struck by the teeth of the revolving wheel B. The number of teeth being known, and the number of revolutions which the wheel B makes in one second of time, it is easy to calculate how many vibrations the card makes during the same time, because this exactly corresponds to the number of times it is struck by the teeth. The machine is set in motion, and when the note given out by the vibrating

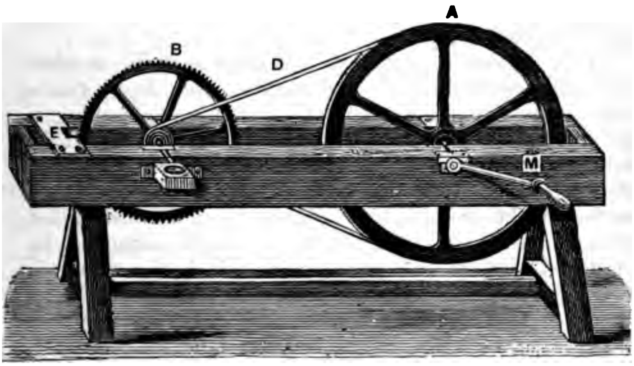


Fig. 39.—Savart's Machine.

card corresponds to the musical note whose wave-length or number of vibrations is required, then the number of revolutions of the wheel B in one second is determined, and this multiplied by the number of teeth, gives the number of vibrations per second which correspond to this note. The velocity of sound being known in air, which we have already seen to be about 1,093 feet, we have only to divide this number by the number of vibrations per second, and it will give us the length or distance which corresponds to the wave-length of the note, and which is really the distance travelled over by the sound during the time that one condensation and rarefaction of the air takes

place. The same results may be obtained by means of an instrument called a *Siren*, where the musical note is produced by the sudden escape into the air of a puff of wind, which is regulated by a suitable mechanism. A plate with a number of holes in it is caused to revolve over a fixed hole, from which the jet of condensed air is escaping, and as the velocity with which these holes in the plate pass over the air-opening is known, it is easy to calculate how many puffs per second correspond to a given note, and these represent so many undulations per second for that note.

150. *Vibration of Strings.*—When a metallic or other string is stretched tight between two points, and a transversal vibration produced in it, by striking or pulling, a musical note is given out, the character or tone of which depends upon the nature, thickness, and tension of the string. When a simple string is caused to vibrate, the surface of the string is so small, and the points of contact with the air so few, that only a very slight sound can be produced; but if the points with which the string is suspended are attached to a large, thin, and flat sounding-board, so that the vibrations can be communicated to a larger area, then the sound becomes loud and distinct. For this reason, all stringed musical instruments are provided with sounding-boards. The laws which regulate the vibration of strings are as follows:—

(1) The rate of vibration is inversely proportional to the length, so that the longest strings vibrate the slowest, and the shortest strings the fastest.

(2) The rate of vibration is inversely proportional to the diameter or thickness of the cord.

(3) The rate of vibration is inversely proportional to the square root of the stretching weight, or tension.

(4) The rate of vibration is inversely proportional to the square root of the density.

The vibrations of a string are like the oscillations of a pendulum, but they do not continue so long under the *action of* the same impulse, because the energy is more

rapidly expended upon the suspending points, and the molecular work performed within the string, than in the case of a pendulum which only has friction against the air. The greater the mass of the string which is moved by the force of tension, the smaller is the velocity produced, and therefore the vibration is slower. On this account the cords are made thicker in musical instruments for the bass than for the treble notes, and for the deepest notes are frequently wound round with thin brass or copper wire to increase their weight.

A stretched wire may be made to alter the time of its vibration, and therefore the note which it will produce, by inserting a stop or rest at any point within the two

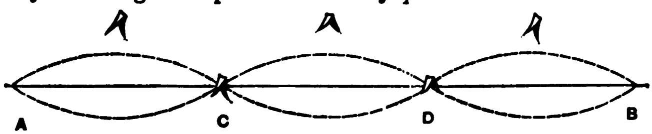


Fig. 40.—Showing Vibration of String clamped at one-third of its length.

suspending points, which will divide the length of the wire into parts such that the ratio between the point to which the stop is put and the end of the wire is represented by any whole number, such as 2, 3, 4, 5, 6, &c. Fig. 40 represents a vibrating string, where the two points of suspension are A and B, and the stop D is inserted at such a distance from B that B D is to B A as 1 is to 3, or one-third the total length. The string then vibrates as if it were only as long as D B, and the remaining portion of the string vibrates also in the same manner as if it had a stop at C as well as at D. When a string is vibrating in this manner, the points C and D are called *nodes*, and the loops between them, which represent the amplitude of the vibration of the string, are called *ventral segments*. A small rider placed on the vibrating wire at C would remain on the wire, but in any other position except a node would be thrown off. When a musical note is sounding in air from

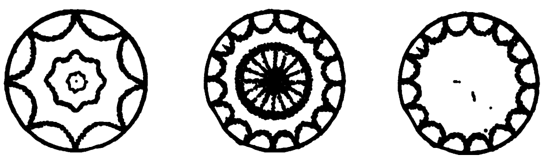
the vibration of a string, or other means, it will excite sympathetic vibration in any string which may be present within the range of hearing; and which, if sounded, would give out the same fundamental note. This may be frequently noticed in the case of a piano where the strings vibrate, or ring in unison with sounds which are produced in the room outside. This phenomenon is called *resonance.*

151. *Natural Scale of Music.*—When any musical note is heard, there is always a series of other sounds, which, from the effect which they produce upon the ear, seem to be related to it in such a manner that they produce the sensation of harmony. These notes form a series which are connected with the fundamental, or *key-note,* in a series of eights or *octaves,* so that the eighth of one series forms the first of the next, and the eighth of any series produces the same mental effect as the first. Upon this law depends the whole of the science of music, which is produced from certain sounds as key-notes, with all their variously associated sounds harmoniously arranged. When the length of any string is taken, which gives a key-note when caused to vibrate, one-half the original length produces the octave, that is, double the number of vibrations which produced the original note; two-thirds of the length makes three-seconds of the original number; and three-fourths of the length makes four-thirds of the original number, &c. In consequence of this law, in instruments of few strings, such as the violin, a great variety of notes can be produced by pressing the strings with the fingers upon the finger-board of the instrument, and thus allowing various lengths to vibrate. The key-note, with its octave and six intermediate notes, is called the *natural musical scale,* or *gamut,* and also sometimes the *major* or *diatonic* scale.

152. *Overtones.*—Whenever any string is vibrating as a whole, or from its total length, it also usually divides into aliquot parts, so that there is always a series of *smaller* vibrations superimposed on the larger, and the

tones which correspond to these smaller vibrations mingle with the fundamental or key-note, which is produced by the vibration of the string as a whole. These additional notes are called *harmonics*, or *overtones*. The production of these overtones is one of the chief causes why musical notes of the same pitch and intensity, but obtained from different sources, differ so much in character, or what is sometimes called *timbre*, or *quality*.

153. *Vibrating Plates.*—When thin metallic plates are made to vibrate by a blow, or other energy communicated to them, they emit a musical sound, and perform a



Figs. 41, 42, 43.—Vibrating Plates.

series of vibratory movements when sounded in different ways. These vibrations, and the nodal lines about which the various parts of the plate vibrate, can be very distinctly seen by fixing the plate at various points, and causing it to vibrate in different ways by drawing a violin bow across the edge of the plate. The surface of the plate must first be covered over with a very thin layer of fine sand. When the plate is caused to vibrate, the sand accumulates on the nodal lines, because there is no vibration there, and by touching the edge of the plate some very beautiful figures may be obtained, as seen in Figs. 41, 42, and 43.

154. *Vibrating Rods.*—A rod which is fixed at both ends vibrates in exactly the same way as a wire, and divides itself in the same manner, so that it can either vibrate as a whole or in a series of ventral segments,

which are separated by nodes, but the rates of vibration and succession of tones are different.

A rod fixed at one end may also vibrate either as a whole or in segments, and a *tuning-fork* is constructed upon this principle. When the fork is vibrating in segments, the succession of tones is the same as in a rod free at one end, but the nodes are different. The musical box is constructed on this principle, where the teeth of the comb are pressed down by the action of a succession of points arranged in proper order on a revolving cylinder, and the vibration of these teeth, when released, produces the musical notes required.

When a rod is free at both ends, it gives its fundamental note when clamped in the centre, and the wave-length is double the length of the rod, while the rate of vibration is the same as that of a rod of the same length fixed at both ends.

155. *Vibration of Columns of Air.*—When we take a tall jar filled with air, and hold a tuning-fork over the mouth of the jar when in a state of vibration, we have the sound of the fork increased by means of resonance. This sound increases or diminishes with the length of the column of air in the vessel, and it is found that the maximum intensity of the sound occurs when the length of the column of air is one-quarter of the wave-length of the fork. The nature of the material which forms the jar enclosing the vibrating column of air has no effect upon the pitch of the note, which is entirely dependent upon the vibration of the column of air itself. This is the principle upon which all wind instruments, such as organs, &c., are constructed, where the notes produced are determined, not by the material of the pipes, but by the length and character of the column of air which they contain. Fig. 44 gives an illustration of an ordinary organ-pipe, where the current of air is forced up-

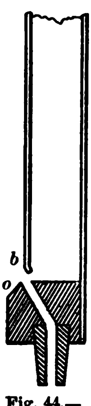


Fig. 44.—Organ Pipe.

ward from the bottom, and in passing outward in a slanting direction, strikes against the lip *b*, and is made thus to issue from the opening *b o* in a succession of pulses or waves. These pulses will no doubt differ greatly in character, but one of them will correspond in wave-length with the column of air vibrating within the closed pipe, and will thus be selected out from the rest, and exalted by resonance into a musical sound. The primary note in such a closed organ-pipe is always found to be that of which the half wave-length is twice the length of the pipe, or the full wave-length, as we have seen in the case of the tuning-fork and jar, four times the length of the pipe. The air within the pipe, therefore, is in a condition such that the greatest amplitude of vibration is at the lip, while the top of the column is stationary; so that the pulse which is exalted is that which performs half a complete vibration in the time that the sound travels from the bottom to the top of the pipe, and back again to the bottom. When an open organ-pipe is used instead of a closed one, the condition of the air within the pipe is very different, since the greatest amplitude of vibration is at each end exactly the same as the vibration of a rod free at each end, and vibrating longitudinally. The wave-length produced by such a pipe is, therefore, only half that which would be produced by a closed pipe of the same length. In the construction of organs, this law acts very conveniently, because it enables notes which require a long wave-length, such as 32 feet, to be produced by a pipe which is only 16 feet long, and thus much space is economised.

156. *The Human Voice.*—The human voice is really produced by the existence of a natural organ-pipe within the throat. The upper part of the wind-pipe terminates in the *larynx*, which is a membranous cavity, which tapers towards the top, and terminates in a small slit called the *glottis*. The membranes which enclose the glottis are acted upon by a series of muscular bands, which are termed the *vocal cords*, and which, when

operated upon by the will, brace up the membranes to any required tension. A small lid or flap, called the *epiglottis*, covers the opening of the glottis, and prevents food from passing into the wind-pipe when food is taken. When the voice is used, a blast of air is ejected from the lungs, and the tightened membranes of the glottis are thrown into vibration, and thus sound or voice is produced. The tension of the vocal cords is greatest when high notes are being produced, and least for the lowest notes. In the mouth, which acts as a resonant cavity, the sound is modulated by the action of the throat, tongue, and lips, and thus we are able to mix together the fundamental note, and the overtones in different proportions, and produce all the variation which is so characteristic of human speech.

157. *Interference of Sound.*—If the surface of a pool of still water be thrown into waves by the dropping of a pebble into it, and another system of similar waves be produced simultaneously, it will be found that wherever these two systems meet each other, in such a manner that the crest of one set of waves corresponds with the hollow of the other, an area of calm is produced by the mutual destruction of the two wave-systems; and wherever they coincide with each other, crest with crest, and hollow with hollow, an increased wave-height is produced. In the same way, when in two systems of sonorous waves condensation coincides with rarefaction, there is a mutual destruction of sound, and silence is the result: and when condensation coincides with condensation, and rarefaction with rarefaction, an exaltation of sound is the result. This destruction of sound may easily be heard by causing a tuning-fork to sound, and turning it round vertically at a short distance from the ear. Four points will be observed where the sound is almost inaudible, and four where the sound is greatest, and this arises from the mutual interference of the alternately condensed and rarefied wave which is produced within and without the *prongs* of the fork. This effect may be very much

increased by turning the fork round horizontally over the mouth of a jar which contains a resonant column of air. The same cause produces the *beats* which are heard when organ-pipes, or other sounding bodies produce wave-lengths, which at certain intervals of time coincide with each other as above, and thus produce silence. The number of beats which will occur in any given time is always equal to the difference between the number of vibrations of the sounding bodies in the same time.

158. *Reflection of Sound.*—When sound-waves are brought into contact with hard and dense surfaces, they are reflected back again in the same way as light from the surface of a mirror. This is often observed in large empty rooms, where the sound-waves are propagated backwards and forwards, since there is no furniture or other objects to absorb the sound, and thus an unnatural exaltation of the voice seems to take place. This is also the cause, often experienced in large public halls, of the difficulty of hearing the speaker, because the reflected sounds and direct sounds reach the ear together, and thus produce either interference or confusion in the ear.

When a regular reflection of the sound is returned, we have the production of what is termed an *echo*, where one or more syllables are returned from a long distance without confusion. This only occurs when the reflected sound reaches the ear one syllable behind the direct sound.

When sound-waves are reflected from concave surfaces, they become concentrated, like the rays of light in the focus of a concave mirror, and are thus exalted in intensity. The beat of a clock, or tick of a watch, placed in the focus of a concave reflector, can thus be heard at a great distance when the ear is placed in the focus of a similar reflector placed opposite to it. The constant reflection of sound within the surfaces of smooth tubes also enables sound to be transmitted to a great distance with perfect distinctness, and it is on this principle that *speaking-tubes* are constructed. Sound-waves can also be gathered up by continual reflection from suitable surfaces,

and the energy of the sound-waves made more available by being concentrated on a smaller bulk of air. We have an instance of this in the *ear-trumpet*, used by deaf persons, and the *stethoscope*, used by surgeons to listen to the action of the heart and lungs. In the latter case, part of the sound is conducted through the material of the instrument.

159. *The Ear.*—So far as man is concerned, the appreciation of sound depends upon the possession of a wonderful organic structure—the *ear*. It really consists of three parts—the outer, the middle, and the inner ear. The outer ear consists of a large gathering surface, which is called the *concha*, and which terminates in a tube entering the side of the head. At the termination of this tube, a thin vibratory membrane, called the *tympanum*, or *drum*, closes the outer ear. A series of bones, which are suspended in such a manner that they are free to move with the vibration of the tympanum, are contained within the cavity of the middle ear, and transmit the motion onward to the *labyrinth*, which constitutes the inner ear. This labyrinth consists of a series of branching and convoluted chambers, which are filled with fluid, and over the surface of which the terminal fibres of the nerves which communicate with the brain are distributed. Large numbers of small crystalline particles float in the liquid in one part of the labyrinth, and in other parts between the nerve-fibres are disposed very fine elastic bristles, which terminate in sharp points. Lastly, within the labyrinth is a wonderful organ, which is really a stringed instrument with 3,000 strings, so arranged as to accept vibrations of different periods, and transmit them to the nervous filaments which traverse the surface to which they are attached. The sounds which reach the ear from the outer world are thus taken up by these floating bodies—vibratory hairs and tense strings—and, however complicated the sound may be, it is analysed by this wonderful mechanism, and transmitted to the brain.

Part IV.

CONDITIONS OF FORCE; FORCE IN RELATION TO MATTER.

CHAPTER I.

LIGHT, INCLUDING A SKETCH OF PHYSICAL OPTICS.

160. *Nature of Light.*—Light is the agent which, by acting upon the retina of the eye, excites in it the sensation of vision, and thus renders objects external to the body visible. That this agent, whatever it may be, is thrown off from the surface of luminous bodies in every direction was known to the ancients, but it is only within comparatively modern times that any attempt has been made to account for the phenomenon. Two different theories were suggested about the time of Newton, and within a recent period a third. They may be termed—

(1) The Corpuscular, or Emission Theory.
(2) The Undulatory, or Wave Theory.
(3) The Electro-Magnetic Theory.

(1) The Corpuscular Theory, which was originally propounded by Newton, supposes that light is the result of the emission from all luminous bodies of an enormous number of minute particles of imponderable matter which are moving with immense velocity, and which, by their impact upon the retina of the eye, excite the sensation of vision. Some of the phenomena exhibited by luminous rays, however, cannot be explained in any way by this theory, and it is now, therefore, considered untenable.

(2) The Undulatory Theory supposes that light

is the result of a series of waves, or undulations, which are produced by the action of luminous bodies in an exceedingly rare medium, which fills all space and interpenetrates the molecular interstices of all matter, surrounding the molecules with an atmosphere which fills up all the intervening spaces. To this exceedingly rarefied and highly elastic medium the name of *luminiferous ether*—or more simply, *ether*—has been given. The molecules of all luminous bodies are supposed to be in a state of the most rapid vibration, and as they are surrounded by this all-pervading ether, they generate in it a series of undulations, or waves, which are propagated from the luminous centre in every direction with enormous velocity. The sensation of vision is thus the result of these undulations of the ether falling upon the retina of the eye, in the same way as the undulations of the sound-waves in air produce the sensation of hearing in the ear. The difference in the nature or colour of light depends upon the length of the waves, or undulations of this ether, and the intensity of the light upon the amplitude of vibration. The average length of the wave of a ray of white light is about $\frac{1}{48,000}$th of an inch, and the number of vibrations of the ray, or passages of the molecules of the ether from a state of motion to rest, about 588,000,000,000,000 (five hundred and eighty-eight millions of millions) per second. Athough there are many difficulties connected with the acceptance of this theory, so far as the nature of the ethereal medium is concerned, yet the perfect success with which it explains all the varied and complicated phenomena produced by the action of light has won for it an almost universal acceptation, and it is now the foundation upon which the whole science of optics is based.

(3) The remarkable coincidence between the velocity of light in air and the velocity of electro-magnetic induction in air and other gases, led Professor Clerk Maxwell to suggest that light itself is probably an electro-magnetic disturbance, and is propagated through space by a series

of tensions along the lines of force and pressures at right angles to them. The relationship which can thus be shown to exist between electrical and luminous phenomena, which in actual practice is found to be so close, and the fact that it enables a mathematical explanation to be given of some effects which are exceedingly difficult to account for by the undulatory theory, give this hypothesis considerable weight. It also explains one of the great difficulties connected with the supposed constitution of the luminiferous ether, which seems to require that none of its elementary molecules—or whatever may form its ultimate structure—can be supposed capable of interchanging places in space when transmitting luminous impulses.

161. *Luminous Rays.*—In every homogeneous medium light is always propagated in a straight line, and the smallest pencil or portion of disturbed ether which is capable of exciting the sensation of light is termed a *luminous ray*, or *ray of light.* When a number of these rays are proceeding from a luminous body, in such a manner that they are parallel to each other, they are termed *parallel rays;* when they separate from each other farther and farther as they proceed onward, they are termed *divergent rays;* and when they continually approach each other they are termed *convergent rays.*

162. *Light in relation to Matter.*—Whenever any solid matter is interposed into the path of a luminous ray, one of three events occurs.

(1) The ray of light is stopped in its progress, and cannot be seen behind the body, in which case the body is termed *opaque,* or *non-transparent,* such as wood or iron.

(2) The ray of light is dimly seen through the interposing body, and it is therefore termed *translucent,* such as ground glass or horn.

(3) The ray of light passes through the object, and the image of any other object is transmitted through it unchanged. In this case we term the body *transparent,* or *diaphanous*

163. *Velocity of Light.*—The ancients thought that the transmission of light was instantaneous, and it was not until the year 1675 that observations made by Rœmer upon the satellites of Jupiter showed that a certain time was required for the light emitted from the surface of these bodies to traverse the immense distance across the orbit of the earth. From these observations, it was supposed to move with the astonishing velocity of 192,000 miles per second, or equal to eight times round the circumference of the earth at the equator. The distance of the earth from the sun being known more exactly now than at that time, it has been necessary to correct this velocity, and it is now found by this method to be about 186,000 miles per second. This determination agrees very closely with the velocity ascertained by a more direct method of measurement taken over short terrestrial distances. This has been undertaken by several observers, and the general method employed has been as follows:—A toothed wheel is so arranged that a ray of light will pass through the interval between two teeth, and passing forward to a mirror, be reflected back again between the same teeth. If, however, the wheel is set in motion with such a speed that the ray of light, reflected back from the mirror, strikes not the interval between the teeth, but the next tooth, and thus is cut off from the eye of the observer, it is quite clear that the ray of light must have traversed twice the distance from the wheel to the mirror during the interval of time required by the wheel to move forward one tooth. The velocity of the wheel is then increased until the ray becomes visible in the next opening, and therefore the double journey from the wheel to the mirror and back to the wheel must have been performed by the ray in the time required by the wheel to pass forward from one interval to the other. The velocity of the wheel being known, this interval of time is also known, and the velocity of light is thus determined for the space between the wheel and the mirror, and, therefore, for any other space. Exact measurements

by this and other methods determine the velocity to be probably a little over 186,000 miles per second. The velocity of light produces a curious effect upon the apparent positions of the heavenly bodies when observed through the telescope. The combined motion of the earth in its orbit and the velocity of light emanating from a star necessitate that the telescope, in order to view the star, shall not be pointed directly to the star, but in an inclined position, so as to allow for the change in the direction of the ray resulting from the combination of these two motions. This phenomenon is called *aberration*. From observations made upon this aberration, the velocity of light has been deduced, and agrees very closely with the result given above.

The velocity of light varies with the medium through which it is passing—being greatest in rare bodies, and least in dense bodies—so that light is retarded in its passage even through a transparent pane of glass. The determination of this fact settled the question whether the corpuscular or the undulatory theory of light was correct, because the former required the velocity to be greater in glass than in air. The undulatory theory requires that the ethereal medium in which the waves are formed should also vary in different bodies, being the most dense in rare bodies and the most rare in dense bodies, so that its elasticity, upon which the velocity of propagation depends, is greatest in the rare bodies, because it increases with the density. It also requires that the velocity of propagation of all kinds of rays should be equal; and should the apparent results of some recent experiments, which seem to indicate a difference, be verified, it may necessitate an alteration in our fundamental conceptions of the nature of the luminiferous ether.

164. *Intensity of Light.*—Light, like sound, suffers diminution in intensity as the distance becomes greater from the source of light; and since, if we take the case of light emanating from a luminous point, it is radiated in

every direction, and at every successive distance covers the area of a larger and larger sphere, it follows that the intensity of light, as affected by distance, varies, like sound, as the inverse square of the distance. If, therefore, any surface is equally illuminated by two lights, which are placed at different distances from it, the relative intensity of the two lights will vary directly as the square of the distance. Upon this principle the art of *photometry* is based, by which we ascertain the number of candles to which a gas flame or electric light is equal. The depth or degree of darkness in the shadow which opaque bodies cast behind them also depends on their distance and relation to the source of light. When light is reflected from a surface, the intensity varies with the angle at which the light is reflected. However intense the light may be, when the eye is not in the direct line of the luminous rays, and there are no reflecting surfaces, the ray is absolutely invisible. This may be seen by permitting a ray of light to traverse a dark box from side to side, and observing at right angles to the path of the ray. If no dust or other floating matter be present, no light will be perceived. The same phenomenon may be observed by looking up into the sky on a dark winter's night, when there is no moon visible. The space beyond the shadow of the earth is flooded with solar light, but the rays are quite invisible without some such surface as the moon to reflect them in the direct line to the eyes.

165. *Reflection of Light.*—When a ray of light is returned into the medium in which it is moving, it is said to be reflected. When the reflecting surface is irregular, the rays of light which fall upon it are reflected in every direction, and this is called *irregular* or *scattered* reflection. When the surface is smooth and polished like a mirror, the reflection is in a constant direction, and the parallelism of the rays is preserved. This is termed *regular* reflection. Regular reflection may occur either [illegible]ane or curved surfaces.

[illegible] *Reflection from Plane Surfaces.*—Whenever a

ray of light falls upon any plane reflecting surface, the ray is reflected into the medium in which it is moving at the same angle to the surface as that at which it fell into it. Thus, in Fig. 45, the ray E D, falling upon the reflecting surface A D B, will be reflected in the path D C, so that the angle E D F will always be equal to C D F. It can easily be proved that any other path between the points C and E and the surface of the reflector, such as C G E, is longer than C D E, and light always takes the shortest path. The laws of regular reflection may, therefore, be summed up as follows:—(1) The angle of incidence is equal to the angle of reflection; (2) the incident and reflected rays are always in the same plane; (3) this plane is always perpendicular to the reflecting surface.

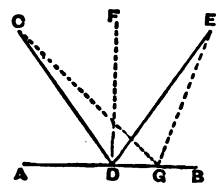


Fig. 45.—Plane Reflection.

167. *Formation of Images by Reflection.*—When any object is placed before a plane mirror, an image of the object is seen in the mirror of the same size and outline, but different in position. Thus, if when viewed in a mirror, the right hand is raised, the image appears to raise the left hand, and *vice versa.* This effect is called *lateral inversion.* Type set up for printing, which in the block is the reverse way to what it will appear when a "proof" is taken, can thus be easily read if it is held in front of a mirror. In a plane reflector also the image always seems as far behind the mirror as the object is situated in front of it. The rays of light from any object at the point A, in Fig. 46, which enter the eye at D D′, by reflection from the plane surface M M, at B B′, appear as though they came from A′, at the other side of the mirror, and it can easily be proved that A′, where the *virtual* image is formed, is the same distance from the mirror that A is, the two lines B A and B A′ being equal. If the reflector is a transparent body, having an appreciable thickness, such as plate glass

silvered at the back, and the object is reflected in it at an angle, a number of outlines are formed by the *repeated* reflection from the two surfaces—the top of the glass and the silvered coat behind with the thickness of the glass between them. On account of this law, if two plane mirrors are placed at some distance opposite to each other, and not quite parallel, the image of, say, a candle viewed in one is reflected backwards and forwards between the two, the image growing less and less as the reflection proceeds. There appears, therefore, an endless succession of candles stretching away into the distance. Since even the surfaces of transparent bodies reflect when the light falls at an angle, some curious results are obtained by superimposing reflected images upon objects seen through the transparent medium. Under suitable conditions both images can be made equally distinct. Upon this principle the construction of "Pepper's Ghost" is designed.

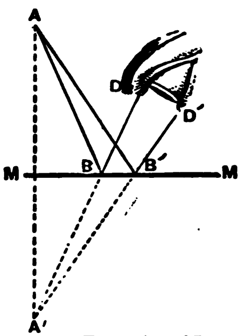


Fig. 46.—Formation of Image by Reflection.

By arranging a number of reflecting surfaces, light may be carried round corners, and thus guns on board ships may be directed toward any desired mark from the deck below or inside a shot-proof turret. Many curious instruments also, such as the *kaleidoscope*, used in designing and also as a toy, are thus constructed.

168. *Reflection from Curved Surfaces.*—Curved surfaces reflect rays of light in the same way that plane surfaces do: viz., that the angle of reflection is always equal to the angle of incidence. The rays, however, after being reflected, are no longer parallel, but converge towards one point, which is called a focus. In Fig. 47, *BD′* is a curved surface, of which C is the centre of

curvature, and C D, C D′, being radii of the same circle, are perpendicular to the surface of the curve at the points D D′. If any luminous object, such as L, give out rays which move in the direction L D, L D′, and strike the curved surface at D and D′, they will be reflected at equal angles to the perpendicular at this point, and concentrate at the point *f*, which is the focus for these rays. Any luminous body placed at *f* will also have its rays concentrated at L, because they will follow the same path as rays proceeding from L. It will be clearly seen that if L be moved nearer to C, the rays, making equal angles of incidence and reflection, will also move the focus *f* nearer to L, until a point will ultimately be reached where L and *f* will coincide; and rays emanating from this point, and falling upon the curved surface, will be reflected back to the same point. The points L and *f* are therefore called *conjugate foci*, because they always bear a reciprocal relation to each other. The point where they will meet in a circular curve will be when they both arrive at the centre of curvature, C. As the point *f* moves nearer to F, the point L will continue to move farther and farther away from the point *f*, but when the point F is reached, which is termed the *principal focus*, the rays which diverge from this point on to the mirror, as shown by the dotted lines, will by equal angles of incidence and reflection leave the surface of the mirror parallel to each other, and consequently will never approach each other, and no focus will be formed at even an infinite distance. If the luminous point move nearer to B from F, the rays will cease to be parallel when they leave the reflecting

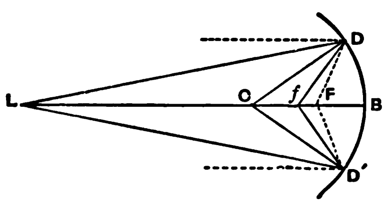


Fig. 47.—Formation of Foci.

surface and diverge out into space. This will be seen in Fig. 48, where F is the principal focus and C the luminous point. The divergent rays, however, when seen by the eye at E, will appear to form a focus behind the mirror at C′. This point C′ is called a *virtual* focus. In Fig. 47 it will also be seen that if parallel rays fall upon the curved surface they will all be reflected to the principal focus F, and concentrated there. The rays from the sun may be taken as sensibly parallel, and if they are permitted to fall upon a curved mirror of this shape, a brilliant point of light is formed at F when any

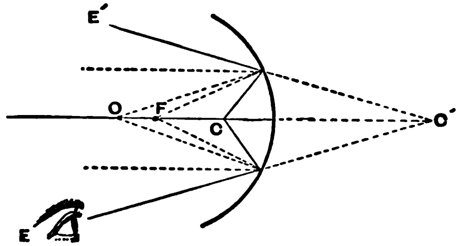


Fig. 48.—Virtual Focus.

surface is placed there to receive it. When the curved surface, however, is large, this reflection of the rays to one focus does not occur, because all the rays do not make equal angles with the perpendicular to the surface at every part of it, and hence the true focussing of the rays to a point only occurs over a small area surrounding the central axis. In actual practice also the rays of the sun are not parallel, because they proceed from every part of the solar surface in every direction, and consequently all the rays which fall upon any circular curved mirror do not all focus at the same point, but at different distances along the line C F, and the crossing of the rays forms a luminous surface, which is called a *caustic* curve. The inability of a concave spherical mirror to concentrate

all the rays falling upon it into one focus is called *spherical aberration.*

When the concave mirror is formed by a curve called the *parabola*, which is one of the sections of a cone, there is no spherical aberration, as the nature of the curve is such that all rays which fall upon it, and which are sensibly parallel, are all absolutely focussed to the same point; and hence, when the rays carry the impression of an object from which they emanate, this image is reproduced on a smaller scale, but much brighter, at the focal point.

169. *Reflecting Telescopes.*—The construction of the reflecting telescopes used for astronomical observations depends upon the above principle. A parabolic reflector is placed at the bottom of the telescope tube, and when the open end of the tube is directed to the heavens, the rays from any celestial object fall upon the mirror, and are concentrated to a focus. In the *Newtonian Reflector*, the converging rays, just before they reach the focus, are received upon a plane mirror, placed at an angle of 45° to the axis of the telescope, and thus reflected through an aperture in the side of the tube, where the image formed is enlarged by the use of a magnifying eye-piece. In the *Herschelian Reflector*, the parabolic mirror is placed at a slight angle to the axis of the tube, so that the concentrating rays, instead of converging round the central axis of the tube, are diverted to the side, and a magnifying object-glass is placed to receive them at the open end of the tube, close to the circumference.

In the *Gregorian* and *Cassegrainian Reflectors*, an opening is made in the centre of the parabolic reflector, at the bottom of the tube, and the rays of light received on the mirror and converging on the central axis of the tube are received on a curved surface, and reflected through the opening in the centre, where the image is magnified by an eye-piece. In the Gregorian form, the small curved reflecting surface has the concave side

turned towards the opening in the parabolic mirror, and the rays falling upon the mirror are allowed to pass the focus before being received and reflected by the concave reflector. In the Cassegrainian form, the small reflector has the convex surface turned towards the eyepiece, and the converging rays are received upon this convex surface before they reach the focus.

170. *Refraction of Light.*—Whenever a ray of light passes out of one medium into another which possesses a different density, the direction of the ray is changed, or bent. This bending of the ray is called *refraction*. This effect is seen in Fig. 49, where A D B marks the surface which divides air above from water below. C D E is a ray of light passing out of the air into the water, and which is seen to be bent towards the perpendicular F G, beneath the surface of the water. The path of the ray, both before and after refraction, is always in the same plane as the perpendicular F G, and the two distances from the perpendicular C F and G E, for the same two media, always bear the same determinate relation to each other, whatever may be the degree of obliquity to the surface of the two media at which the ray falls. This constant relationship is called the *refractive index*, or *index of refraction*, and is found by dividing the sine of the angle of incidence, C D F, or the line C F, by the sine of the angle of refraction E D G, or the line G E. When a ray falls perpendicular to the surface of the two media, it suffers no refraction, and when it falls at a very acute angle, which angle differs for different media, it will not pass from one medium into the other, but is entirely reflected at the surface. The angle at which total reflection

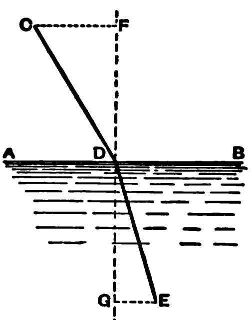


Fig. 49.—Refraction.

occurs is called the *critical* angle. The ray is always most refracted when passing out of a dense into a rare medium, and least when passing out of a rare into a dense medium. It is on this account that if a long rod is pushed into clear water it appears to be bent beneath the water. In the same way the rays of the sun when on the horizon are bent upwards by the dense atmosphere through which they pass to the eye, and the round disc of the sun looks both larger and slightly distorted, and is thus visible some time before the sun is above, or after it has sunk below, the horizon. On the same principle the *mirage* is formed which is sometimes seen in sandy deserts and on the sea, where ships and houses and trees are seen suspended in the air. The rays proceeding from the real objects are totally reflected within the atmosphere, and bent by refraction through successive strata of air until they enter the eye at a distance, and seem to be proceeding from an object high in the air. When the rays cross each other during refraction, the image is inverted.

171. *Refraction through Prisms.*—When a ray of light is permitted to pass through a transparent prism of glass, it suffers refraction both upon its entrance into the prism and its passage out of it, and thus the path of the ray is changed in direction entirely.

A section of a prism is represented in Fig. 50 by the lines *a b*, *b c*, *c a*. The ray of light, D E, falling upon the prism in the direction D E F, is refracted in the prism into the direction E E′, and upon passing out of the prism into the air again into the direction E′ D′. The angle F G D′ is called the *angle of deviation.*

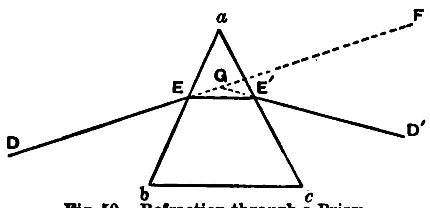


Fig. 50.—Refraction through a Prism.

The degree of deviation from the straight path which any ray of light experiences in passing through the prism depends upon the nature of the material of which the prism is made. Sometimes prisms are made of thin glass walls, and filled with various highly refracting liquids. The degree of deviation of the ray of light also depends upon the angle of incidence of the ray upon the face of the prism, upon the angle of the prism, and upon the colour of the light. If two prisms are placed base to base, and a series of rays of light are allowed to fall upon one side of them, they each bend the rays which pass through them in the same way as single prisms, but in opposite directions, so that the diverging rays converge towards each other. If a solid is formed by the revolution of a plane whose section is two prisms placed base to base upon the shorter axis, we obtain a circular figure, whose centre is the thickest part, and tapering off to the edges. The two faces are ground and polished to take away the angle at the point of junction of the two prisms, and they then form there a circular disc, whose section is like the figure formed by two circles which cut each other, as in Fig. 51, called a *lens.*

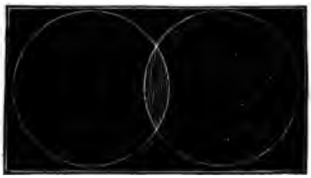


Fig. 51.—Formation of Lens.

172. *Refraction through Lenses.*—When a series of parallel rays fall upon such a lens, then the rays on emerging from the other side are refracted unequally, in consequence of the varying form and thickness of the different parts of the lens, and meet at the point F. The centre ray is unchanged in direction, and the rays are more and more bent as we proceed to the edge. When the system of rays which fall upon the lens is not parallel, as would be the case in Fig. 52, if the rays were radiated from the point F, they would in passing through the

prism be rendered parallel. If, however, the point F were removed farther from the face of the lens, the rays from it would fall upon the surface of the lens at a different angle, and upon emerging from the other side of the lens, the rays, instead of being parallel, will converge towards a centre, and thus a focus will be formed on both sides of the lens. This will be clearly seen

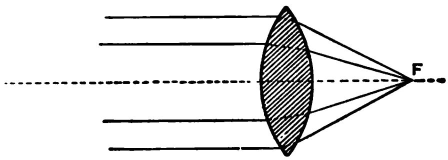


Fig. 52.—Refraction through Lens.

in Fig. 53, where A and A′ are the two foci which, since they are mutually interchangeable, are called *conjugate foci*, in the same way as we have seen two foci formed in front of a curved reflecting surface. The points F and F′ are called the *principal foci*, because

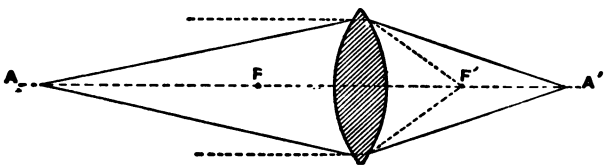


Fig. 53.—Formation of Foci by Lens.

luminous rays falling upon the lens from either of these points would be rendered parallel to each other by refraction through the prism, and parallel rays falling upon the face of the lens would converge after refraction to these points.

If the luminous point is moved nearer to the face of the lens than the principal focus, F or F′, then the rays of light after refraction through the lens diverge from each other.

For different optical purposes lenses are made in

different forms, the various sections of which are shown in Fig. 54, where A is called a double convex lens, B a plano-convex, C a concavo-convex, or meniscus lens. These three are called *converging lenses*. The other three are *diverging lenses*, and are named: D a double concave lens, E a plano-concave lens, and F a concavo-convex lens.

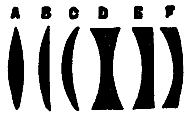


Fig. 54.—Forms of Lenses.

173. *Formation of Images by Lenses.*—Whenever a luminous object, such as a candle, or any object from which luminous rays are being reflected, is placed at a farther distance from the face of a double convex lens than its principal focus, we have the formation of an inverted image of the object when the eye is placed on the other side of the lens. This will be seen in Fig. 55, where the object A B is reproduced at A′ B′ on the other side of the lens, and the relative size of the image and object will be as A C to C A′. Since the object is beyond the principal focus of the lens, the image will always be smaller and inverted. In consequence of the form of the lens, the rays which fall upon the surface from any distant object do not strike it at the same angle, and consequently do not all pass out at the other side and become focussed exactly at the same point; and hence the image formed at the back side of the lens does not look perfectly flat, but is curved in the direction of the surface of the lens. This distortion of the image is termed *spherical aberration*, and has to be corrected by suitable means in the construction of optical instruments. More distant objects are brought to a focus nearer to the lens than those which are close at hand, and hence in the

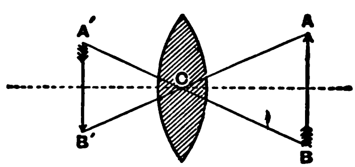


Fig. 55.—Formation of Image by Lens.

nera obscura, which is used for photographic purposes, is necessary that all the objects which are to be otographed shall be as nearly as possible in the same ne at the same distance, or else a more or less con-ed image is obtained at the focus of the lens.

When the object viewed through the lens is nearer the lens than the principal focus, then a magnified age is obtained in the eye, because the rays proceeding m the object are refracted in the lens, and their ection entirely changed, as will be seen in Fig. 56, ere the rays, ering the at the us of the s, appear to ne from A′ although y are really oceeding m A B. Un- these cir-nstances the age is al-ys magnified and erect. This is the construction the *simple microscope*. The *compound microscope* formed by a series of lenses, as seen at Fig. 57, ere the rays which proceed from a luminous object O are made by the united action of a number of npound lenses, called the *object glass*, to diverge upon ens placed at F F, which concentrates the rays to a us, and thus produces an image of the object. This gnified image is itself viewed through a lens, E E, ich concentrates the rays into the eye, and thus ther magnifies the image. The combination of lenses and E E is called the *eye-piece*.

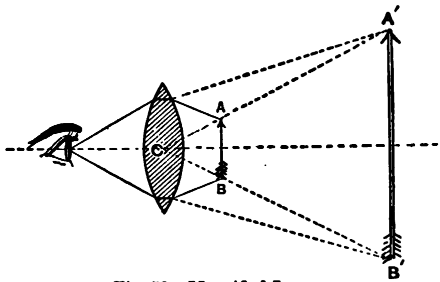


Fig. 56.—Magnified Image.

174. *The Refracting Telescope.* — The difference ween the simple microscope and the telescope is, that the microscope we examine the object itself by means

of a magnifying lens, while in the telescope we examine by a simple microscope an image of the object produced in the focus of another lens.

Fig. 57.—Compound Microscope.

The construction of the astronomical telescope by means of refracting lenses is therefore very simple. It consists of a double convex lens, called the *object glass*, in the focus of which an inverted image of any distant object is formed, and this image is magnified by the use of another similar lens placed so that the image is viewed within the principal focus, and therefore magnified. This will be seen in Fig. 58, where an inverted image of the distant object, A B, is reproduced at A′ B′, within the focus of the eye-piece, which concentrates the rays into the eye, E. In consequence of the refraction of the rays within this eye-piece, the rays appear to the eye to come from an object placed beyond the focus at A″ B″, and therefore much larger. When used for astronomical purposes, the inversion of the object makes no difference, but when used for terrestial objects a compound eye-piece is used to magnify the image. Into this eye-piece two additional lenses are introduced, which reverse the image into its original upright position. The introduction of these additional lenses, however, diminishes the brightness of the image produced in the eye by causing a loss of light.

175. *The Eye.*—The eyes are really a system of two lenses, which operate together at an angle, so that the appearance of solidity in objects, which is called *stereoscopic vision*, is obtained. Each eye consists of a globular chamber, in the front of which is an opening filled in

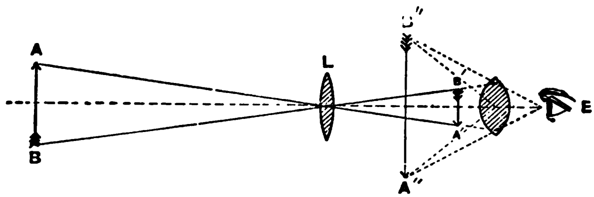


Fig. 58.—Refracting Telescope.

with a double convex lens, C, called the *crystalline lens*, as seen in Fig. 59, which concentrates the rays of light coming from a distant object, A B, on to the back of the dark chamber at *b a*. The surface upon which the rays are thrown, and upon which an image of the object is projected, is covered with a fine network of nerves, and is called the *retina*. These fine nerves all communicate with one main nerve, called the optic nerve, which

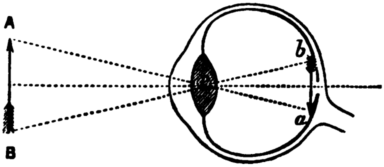


Fig. 59.—Human Eye.

passes through an opening at the back of the eye below the point where the light falls, and thus communicates to the brain the sensation of vision. In front of the lens is a transparent membrane, called the *cornea*, which converges the light upon the lens behind, and between the two is a diaphragm with a circular opening, called the *iris*, which can expand or contract, so as to regulate the amount of light passing into the eye. This iris differs in colour in different individuals, and hence the various

colours of the eye. The eye in all its various parts is acted upon by a set of muscles, so that the direction of its axis can be changed, and the degree of convexity of the lens slightly changed also, so as to regulate the focus for near or distant objects. With advancing age the form of the lens is often altered, and the rays of light cannot therefore be properly concentrated on to the retina, and this necessitates the use of an extra lens, which differs in form for different cases, so as to rectify the defect. These lenses are called *eye-glasses*, or *spectacles.*

176. *Dispersion of Light.*—So far, we have con-

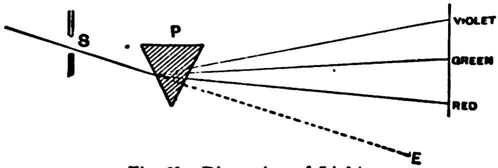


Fig. 60.—Dispe.sion of Light.

sidered the action of lenses or prisms upon the light as uniform for all kinds of light; but in reality this is not the case, for the different colours of light are unequally refracted by the same prism. The prism, therefore, becomes the means by which we can separate the various colours which form a ray of white light in the order of their wave-lengths, upon which really depends the difference in colour. If we permit a ray of light to pass through a small hole in a shutter, as at S in Fig. 60, and fall upon the side of a prism, P, the component parts of the ray are unequally refracted in their passage through the prism. Not only is the direction of the ray changed from the path S E, but it becomes opened out like a fan, and the violet-coloured light is refracted more than the green, and the green than the red. This phenomenon is called the *dispersion of light*, because the various component parts of the ray are scattered or dispersed. The

order of dispersion for all colours, beginning with the most refrangible, is violet, indigo, blue, green, yellow, orange, and red. By means of a number of prisms suitably arranged, this dispersive action can be very much increased, and the coloured band of light made to extend over many feet, so that each colour can be examined separately. Upon this principle the *spectroscope* is formed, which has become one of the most powerful analytical instruments in the hands of the physicist, and of which more will be said hereafter.

If, instead of using one prism alone to pass the ray through, or a number of prisms placed in the *same* direction, a second prism be used turned the *opposite* way up, as in Fig. 61, then the various colours are re-combined by the refraction of the second prism, and a beam of white light issues from the opposite side.

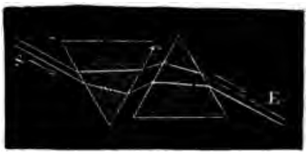


Fig. 61.—Re-composition of Light.

In consequence of this dispersive action, when a ray of light is sent through a lens, the light is more or less dispersed, and the parts of the ray which are most refracted are brought to a focus nearer the face of the lens than those which are less refracted, so that there is a series of foci which are scattered over a considerable distance, which depends upon the form of the lens. This will be clearly seen in Fig. 62, where the rays of light passing through the double convex lens are focused over the whole distance from A to T, the most refrangible violet rays being focused at A, while the least refrangible red rays concentrate at T, and all the other colours are

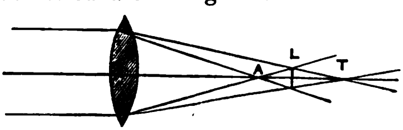


Fig. 62.—Unequal Refraction.

intermediate. This phenomenon is called *chromatic aberration*, and was one of the difficulties which for a long time hindered the use both of the refracting microscope and telescope, by causing indistinct and coloured images.

177. *The Achromatic Lens.*—To avoid the defect and inconvenience occasioned by chromatic aberration in the construction of optical instruments, the lens is formed of two different kinds of glass, called *crown* glass and *flint* glass, which are made of a suitable form to fit each other accurately, and cemented together by a transparent gum. The effect of the second lens is to act the part of the second prism, and re-blend the coloured rays into a white ray, while at the same time, by suitably proportioning the lenses, a sufficient quantity of refraction or bending power is retained to concentrate the rays to a focus. Fig. 63 is a half section of such an achromatic lens, where C is the crown glass and F the flint glass lens, forming together a plano-convex lens, B. The ray of white light, W, is decomposed in passing through the crown glass lens, and re-composed again in passing through the flint glass, while the combination still retains a sufficient amount of refractive action to cause the emerging ray to be bent towards the central axis, and thus form a focus, when the colour is almost entirely absent. The sensation of white light is the average effect produced on the retina by the impact of luminous vibrations of all wave-lengths. This can be distinctly shown by taking a disc whose surface is coloured the

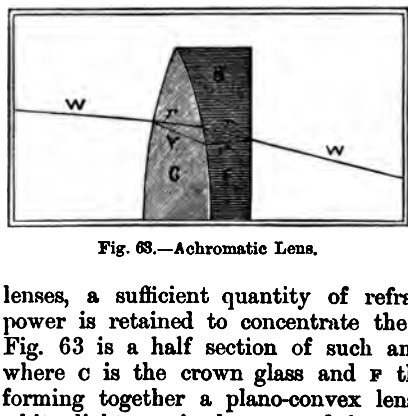


Fig. 63.—Achromatic Lens.

various colours of the spectrum, in segments which are divided by radii of the circle. When at rest, each separate coloured segment is visible to the eye with its distinctive colour, but when the disc is caused to revolve rapidly, the whole surface appears to be white. These achromatic lenses are now universally used, and have greatly contributed to the present perfection of all optical instruments.

178. *The Spectroscope.*—This instrument consists

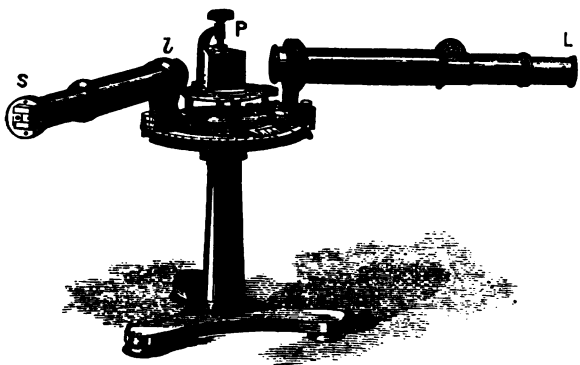


Fig. 64.—Spectroscope.

of a prism, or series of prisms, so as to increase the dispersion, the light thrown upon which is passed through a narrow slit, to prevent any overlapping of the colours, and after passing through the prism is received into an observing telescope, by which a magnified image of the coloured band is obtained. Fig. 64 represents a simple form of this instrument, where the light proceeding from any source is passed through a narrow slit at S, the box, D, into the axis of the telescope, S L, and allowed to fall upon the prism, P. A small screw regulates the width of the slit to any required degree. The observing telescope, L, is placed at a

suitable angle to the axis of the telescope, S L, so as to receive the refracted rays which have passed through the prism. The reason why the telescope, S L, is used is to render all the rays which are received from the slit parallel before they fall upon the face of the prism. If we examine the rays of light which proceed from an incandescent solid, such as the lime-ball in the oxyhydrogen light, we find that the coloured band or spectrum, as it is called, which is seen in the field of the observing telescope, is continuous—that is to say, that the various colours from red to violet, through all the variations of colour, shade into each other so gradually that we cannot say where one begins and the other ends. If, however, we examine the light from the sun, we find this is not the case, as the whole spectrum is barred across at right angles to its length by a series of dark lines, as seen in Fig. 65. These lines always occupy the same relative position, and differ in width and distinctness, and in their distribution in the various colours. They are called Fraunhofer's lines, from the German philosopher who first mapped out their positions, and they are all distinguished by a letter of the alphabet, such as A, the line in the extreme red, D the two lines in the yellow, or H in the extreme violet. The cause of this discontinuity in the solar spectrum arises from the fact that the rays of light from the bright photosphere of the sun pass through the solar atmosphere, in which the vapour of various bodies and various gases are present, and these vapours absorb or stop the rays of light which have a certain wave-length, so that when the beam or ray is analysed by the spectro-

Fig. 65.—Solar Spectrum.

scopic prism there are no rays present of the degree of refrangibility represented by these lines. It has been found that all incandescent gases and vapours give out rays of a definite degree of refrangibility for each substance, and hence, if we examine the light proceeding from any incandescent gas, we have not a continuous spectrum, but a reversal of the dark lines in the form of a series of bright lines, which are constant for each substance under the same conditions. This discovery enabled physicists to determine the position of the bright lines for most of the elementary substances when in a state of gas, and by super-imposing these bright lines upon the dark lines of the solar spectrum, to see to what substances in the solar atmosphere these dark lines owed their origin. The composition of the solar atmosphere, therefore, became known, and we can feel that this knowledge is based upon as exact determination as if it had been analysed in a laboratory. Some of the lines are found to owe their existence to the water-vapour, oxygen, nitrogen, and other gases which compose our own atmosphere. This method of spectral analysis has been extended to the light of the fixed stars, nebulæ, and comets, and has revealed the fact of the identity of many of the elementary substances in various parts of the universe. It also furnishes a means by which the most minute quantities of any substance can be detected; and, more recently, has also proved the means of determining that a difference exists in the molecular arrangement of various substances, which are the same in their chemical constitution. The general results arrived at by spectroscopic observation may be summed up in three general laws.

(1) Solids, liquids, or dense gases, when in a state of incandescence, give out a continuous spectrum.

(2) Solid or liquid bodies, when rendered gaseous by heat, or incandescent gases at ordinary pressures, give out a spectrum which consists of bright lines only; and the number and position

of these bright lines is different for each substance, and constant for the same substance under the same conditions.

(3) When light which gives a continuous spectrum passes through any gas or vapour, the gas absorbs those rays only which it gives out when itself incandescent.

179. *Ultra-spectral Rays.*—Light from the sun is always accompanied by heat, and also the power to break up or decompose certain chemical substances, and it has been found that both these properties are dependent upon the existence of rays whose wave-lengths differ from

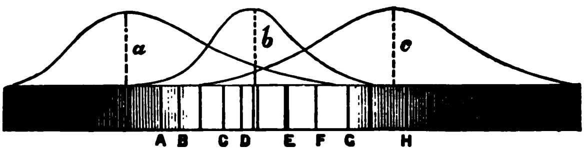


Fig. 66.—Ultra-spectral Rays.

those of light, and have, therefore, a different degree of refrangibility. If we take a solar ray, and pass it through a suitable prism, it is found that the majority of the heat rays are less refrangible than light, and are therefore arranged by the prism beyond the red rays; while the rays which have the power to exert chemical action are more refrangible than the light, and are therefore extended beyond the violet. Fig. 66 illustrates the position of these *ultra-spectral rays* A. The uncoloured dark spaces beyond the red rays at A and the violet rays at H represent the heat spectrum and the chemical or *actinic* spectrum respectively, and the curved lines above indicate by the height of the summit of the curve the maximum points of action in each case. The light is most intense just beyond D in the coloured spectrum, and is indicated by the height of the line *b*, while the heat is greatest at the point beyond the red indicated by the

line *a*, and the actinic power greatest at the point indicated by the line *c*, just within the violet. Different substances possess different powers of transparency to these several kinds of rays, and if suitable means are employed they can each be separated from the others. When the heat is separated from the light and actinic rays, it is capable of concentration, until it will render any substance upon which it falls incandescent, and thus light is produced. This phenomenon is called *Calorescence*, the invisible heat rays being by concentration changed into light by having their refrangibility increased. When the actinic rays are obtained separately, and passed through various chemical solutions, such as a solution of quinine or turmeric, their refrangibility is decreased and their wave-length increased, and they appear as a violet light when passing out of the quinine, and green when out of the turmeric. This phenomenon is called *Fluorescence*. Heat, light, and actinism, therefore, only differ from each other in the length of the waves of ether which produce them. When the wave-length exceeds about $\frac{1}{39000}$th of an inch, it becomes invisible to the eye, but produces a heating effect, and when it is less than about $\frac{1}{57000}$th of an inch, it also ceases to affect the eye, but will act upon various bodies chemically. The wave-lengths of all colours of light rays lie between these two extremes.

180. *Interference of Light*.—We have already seen that when two waves of sound are brought together in such a way that the area of condensation in the one coincides with the area of rarefaction in the other, the two systems neutralise each other, and silence is the result. Also that when the two systems coincide so that the area of rarefaction in both come together, and also the areas of condensation together, there is an increase of sound. In the same way, when two systems of luminous waves or vibrations of light are brought together, so that the crest of the wave of one set coincides with the hollow of the other, we have a mutual destruc-

tion of the two systems, and darkness is the result. When, on the other hand, the waves coincide wave-crest with wave-crest, and hollow with hollow, we have an increase of the light. If the coincidence is not always exact, but only occurs after a certain interval of time, we have a luminous phenomenon occurring similar to the case of *beats* in music. This mutual destruction of luminous waves is called *interference*, because the wave-motions interfere with each other. We have already seen that all the various colours of light differ in wave-length, and that it is the average result of the influence produced by all of them from red to violet which gives the sensation of white light. When, therefore, in any ray of white light falling upon any surface, the molecular structure of which causes some of the component wave-lengths to interfere with each other, we have the mutual destruction of some of the coloured waves, the reflected light ceases to contain every colour, and the sense of white is destroyed, and a series of colours takes its place, which depends upon the extent of the interference. This will be distinctly seen if the rays of the sun are permitted to fall obliquely upon a surface of glass or metal upon which a number of very fine lines have been engraved, since a beautiful play of colours will radiate from the ruled surface to the eye.

181. *Diffraction.*—We have seen that light moves in straight lines, but under certain circumstances, such as when the luminous waves are caused to fall upon the sharp edge of an opaque body pushed into the path of the beam, at right angles to the direction of its motion, there occurs a phenomenon called *diffraction*, or *inflection*, by which the waves of light suffer a lateral propagation, and are bent round the corner of the obstructing solid into the shadow. A series of coloured bands or fringes is thus produced, which will easily be seen by holding up the edge of a card into the path of a beam of light which has been reflected from the surface of a glass mirror, through an opening in a shutter, and con-

centrated by means of a double convex lens. Fig. 67 will show this arrangement, where A is the opening, and reflecting mirror, L, the lens concentrating the light to the focus at O, and producing a diverging beam, into which the obstruction, B, is placed. If the light is received on to a screen, the coloured bands penetrating into the shadow of B will be distinctly seen. If the opening is closed with a red glass, the colours will disappear, and a series of red and black bands take their place. A blue glass will give similar results, with blue instead of red, but the lines will be narrower, because the waves of blue light are shorter than red.

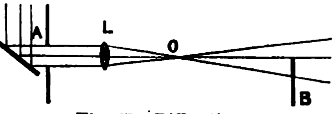


Fig. 67.—Diffraction.

A spectrum can be obtained by diffraction from the surface of a series of lines cut in a plate of glass of much greater equality in the distribution of the colours than by means of refraction through a prism, because in the latter case the nature of the dispersion of the different colours depends upon the nature of the material out of which the prism is formed, and certain parts of the spectrum are crowded into less room than other parts. This unequal effect of dispersion by different substances is called the *irrationality* of dispersion.

When light is reflected from surfaces which are formed by a series of thin transparent plates, such as mother-of-pearl, or of thin films which reflect the light from both surfaces, a series of coloured bands are formed like those visible in the soap bubble. This arises from the fact that the two systems of waves reflected from the two surfaces are not in the same phase of undulation, since the one has been retarded in its passage through the transparent medium from its under surface, and mutual destruction of the systems is the result, producing colour where white light is employed, or dark and light bands if one kind of ray only is used.

182. *Double Refraction.*—When light is permitted to pass through certain transparent crystals, such as Iceland spar (carbonate of lime), the molecular structure of which is different in different directions, the ray of light is divided into two parts, one of which is more refracted than the other. This dividing of the ray is called *double refraction.* If a spot of ink be viewed through such a crystal, it appears double, and if the crystal is turned round, one image of the spot revolves round the other, and one appears nearer to the eye than the other. The image which appears to be fixed is called the *ordinary* image, and the one which revolves round it the *extra-ordinary.* The cause of this phenomenon is that the ray of light is more retarded in one direction of the crystal than in others, and hence is more refracted. All double refracting crystals possess one direction in which the ray of light suffers no double refraction, and some crystals two such directions. This direction is called the axis of the crystal, because around this line of direction the molecular groups are arranged. Crystals with one direction only, in which double refraction does not occur, are called *uniaxal* crystals, and those which possess two *biaxal* crystals.

183. *Polarised Light.*—When a ray of ordinary light is permitted to pass through a thin plate of a transparent mineral called tourmaline, which has been cut parallel to the axis of the crystal, the light undergoes a remarkable change. To the eye it appears exactly the same, but if another plate of tourmaline, cut in the same direction, is placed in the path of the ray, with the axis of the crystal at right angles to the axis of the other plate, the light will not pass through this second plate, although it is quite transparent to ordinary light. When the second plate is turned slowly round on the axis of the ray of light, the light begins to appear, and increases in brightness until the two axes of the two plates of tourmaline are in the same direction, when the light is perfectly transmitted. During a complete revolution of

one crystal over the other, the crystals are twice parallel, at 0° and 180°, and twice at right angles, at 90° and 270°, and in the two former positions the ray of light is completely transmitted, and in the two latter completely suppressed. In all other positions the light is only partially transmitted. It is evident, therefore, that the ray of light in passing through the first plate of tourmaline has undergone a change which prevents its passage through the second plate with facility, except when that plate is in a certain direction. This double-sidedness of the ray is termed *polarised* light, because of a fancied relation to the double character of the ends of a magnet. The first plate of tourmaline, which changes the character of the ray of light from ordinary to polarised light, is called the *polariser;* and the second plate of tourmaline, which reveals the nature of the change which the light has undergone, is called the *analyser*. A ray of polarised light is supposed to differ from an ordinary ray of light in this respect, that all the vibrations or undulations of the ray occur in one plane, while in a ray of ordinary light the vibrations take place in all directions across the axis of the ray, or the direction of its propagation. When a ray of ordinary light is therefore passed through any polariser, the vibrations in every direction except one are quenched within the polariser, or, at any rate, not transmitted through it, and in the emergent beam all the vibrations lie in one plane. When the analyser is presented to such a beam of polarised light, the vibrations being all in one plane, they will pass through the analysing plate whenever the direction of the molecules of the plate coincide with those in the polarising plate, and when at right angles to this position the light will be quenched, just in the same way as all the vibrations which were not in this plane were suppressed in passing through the polariser. In all intermediate positions part of the light will be transmitted, and part suppressed. In addition to polarising light by passing it through a plate of

tourmaline, we may polarise it by any of three other methods—(1) by reflection; (2) by simple refraction; and (3) by double refraction.

When a ray of light is passed through a double refracting crystal, the two beams of light into which the original ray is divided are both found to be polarised when examined by an analyser, but the planes of vibration of the two beams are at right angles to each other, so that when the analyser is in such a position that it transmits the one it quenches the other. For optical purposes, when a ray of polarised light is required, it is usually obtained by double refraction within a crystal of Iceland spar, which is a mineral of great transparency and purity of colour. The crystal is usually arranged in the form of what is known as a Nicol's prism, from the name of the inventor, and of which Fig. 68 is a longitudinal section.

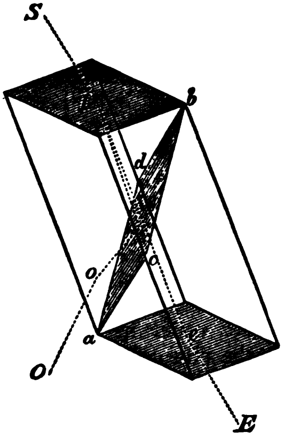


Fig. 68.—Polarising Prism.

The crystal is cut through obliquely in the direction *a b*, parallel to the principal plane, and the two halves cemented together with Canada balsam. The index of refraction of this substance is intermediate to the indices of the two parts of the doubly refracted ray. When, therefore, a ray of ordinary light enters the prism at I, it is divided into two beams, O and E, which are polarised in planes at right angles to each other. The ray O encounters a medium which has a less refractive power than itself, and falls, therefore, upon it at a very oblique angle of incidence, and is totally reflected out at the side of the prism. The ray E, on the other hand, is polarised in the

opposite plane to O, and encountering a medium which has a greater refractive index, passes through it, and emerges at E, at the lower end of the prism, as a ray of perfectly polarised light. Another similar prism may be used as an analyser to examine this ray, which will be transmitted or suppressed according to the position which the layer of Canada balsam occupies in regard to the plane of vibration of the ether molecules in the ray. An instrument which possesses a polariser and analyser for the purpose of experimenting with polarised light is called a *polariscope.*

When two rays are polarised in the same plane and in opposite phases of vibration, they produce by their interference fringes of the same kind as ordinary light; and when two rays, polarised at right angles to each other, are brought into the same plane, they produce the same phenomena, provided they originate in a ray the whole of which was originally polarised in one plane. So long, however, as two rays are in opposite or rectangular planes of polarisation, they never produce any interference, but at intermediate planes of polarisation they produce fringes of intermediate brightness, increasing in intensity from 90°, where they are in rectangular planes, to 0°, where they are in the same plane. With the use of a polariscope, and a plate of selenite between the polariser and analyser, many beautiful effects are produced in sections of double refracting bodies by the interference of the rays of polarised light; and this means also enables us to study with very great exactness the existence of pressures or strains in the molecular structure of transparent bodies.

When a pendulum which is freely suspended, and vibrating in any given plane, has a direction of motion given to it at right angles to its plane of motion, the bottom of the pendulum will describe not a line, but a curvilinear orbit, the nature of the orbit being determined by the quantitative relation of the two directions of motion. When the motions in the two directions are

equal during the same time, the orbit will be a circle; when they are not equal, an ellipse will be described, the major and minor axis of which will bear the same relation to each other as the respective motions in the two directions. In the same way, when we decompose a ray of plane polarised light into two rays of equal intensity, polarised at right angles to each other, and differing in their path by a quarter of a wave-length, we obtain a ray of light in which the vibrations of the ether molecules are executed in circles, and hence we term the ray *circularly* polarised. When the undulations differ by more or less than a quarter of a wave-length, the light is *elliptically* polarised.

Some crystals possess the power of changing the direction of the plane of polarisation of a ray of plane polarised light in passing through them, so that it is sometimes twisted to the right and sometimes to the left—the degree of twisting depending upon the thickness of the plates of transparent substances employed. This phenomenon is called *rotatory polarisation.*

CHAPTER II.

HEAT.

184. *Nature of Heat.*—We have already seen (179) that when the energy radiated from the sun or any other radiating source is refracted through a prism of suitable material, the actinic rays, or those rays which possess chemical activity, are the most refracted. The rays of light broken up into the series of undulations which give the sensation to the eye of colour occupy an intermediate position, and beyond the least refrangible luminous or red rays we have a dark band of heat rays,

which possess the power of acting upon a delicate thermometer, and thus indicate their presence. *Radiant heat*, therefore, differs from luminous or actinic rays according to the undulatory theory only in degree—the undulations of the ether which cause the sensation of heat having a longer wave-length, and occupying a longer time in the performance of one undulation than rays of light or actinism; but they are all undulations of the same all-pervading ether. *Absorbed heat*, or that condition of material which is induced by the impingement of radiant heat upon matter, and which makes itself manifest to our senses by what we term a rise in temperature of the body upon which it impinges, differs entirely in its nature from radiant heat. Two theories have been propounded to account for the phenomena, and they may be termed respectively the *material* and the *dynamical* theory.

185. (1) *The Material Theory* supposes that heat is a species or kind of matter, which differs from ordinary matter in this respect: that it possesses no weight, or is *imponderable*, and that it surrounds the molecules of all matter which is ponderable like an atmosphere, and that, in consequence of the mutual repulsion of its own molecules, and their attraction for the molecules of other matter, this heat matter can easily pass from the interior of one mass of matter to that of another. This theory also regards the condition of radiant heat as similar to the condition supposed by the corpuscular theory of light (160), viz., an emanation of the imponderable molecules of heat from the surface of the radiating body into the surrounding space. This theory, like the corpuscular theory of light, has, however, now been generally abandoned, because it fails to account for many of the phenomena which are observed, especially such as the interference and polarisation of heat, and the production of heat by the stoppage of mechanical motion.

186. *The Dynamical or Mechanical Theory* of heat supposes that the phenomena of absorbed heat, or the absolute temperature which all bodies possess, arise from

a particular condition of the molecules of the body, in virtue of which they are in a state of constant vibration. The amplitude of the vibration determines the temperature of the body, but the motion even in the hottest bodies is too small to be detected by the eye, even when aided by the most powerful microscopes. The motion of the molecules at the surface of any hot body is communicated to the ether by which the body is surrounded, and this motion of the ether constitutes the radiant heat which is thrown off from the surface of all hot bodies into the surrounding space. Thus any hot body which has no source of heat contained within itself, or which is not receiving a supply of heat radiated from some other hot body, will gradually became cooler, because the motion of its molecules is gradually brought to rest, or expended in communicating motion to the ethereal medium which surrounds it. In the same way, any cold body which is receiving radiant heat from any hotter body becomes itself hotter, because the motion of the molecules of the ether is communicated to the molecules of the cold body, and their amplitude of motion is increased, and therefore their absolute temperature. In the same way, when the motion of a mass of matter is suddenly arrested, such as a cannon-ball by its impingement upon the target, or a railway wheel by its friction on the rail when retarded by the application of the brake, the motion of the mass as a whole is transferred to the motion of the molecules of which the mass is composed, and both the cannon-ball and target, and the wheel and rail upon which it slides, are heated.

Although in solid bodies the motion of the molecules which constitute the cause of the sensible temperature cannot be detected by the eye, yet they usually, when the heat is increased, also increase the whole volume occupied by the body, and we then speak of it as *expanding* under the influence of heat; while, when the body is cooling, and the motion of the molecules becoming less, the whole volume occupied by the heated body becomes less, and

we speak of it as *contracting* under the influence of a cooling action. In gases where the fixity of the molecular centres is destroyed, and the motions of the molecules much greater than either in solids or liquids, the expansion under the influence of increase in temperature is much greater; and when the gaseous volume is restrained from expansion by the rigid walls of a containing vessel, then the pressure of the gas upon the surface of the vessel is proportionally increased. All substances which are known to exist upon the surface of the earth possess a motion of their molecules, which is represented by their temperature, and which can be communicated through the surrounding ether to a colder·body. If it was possible to permit this cooling action to be carried so far that the motion of the molecules of the body was entirely arrested, we should probably have an *ultra solid* condition of matter, which would differ from ordinary conditions of solid matter as much as liquids and gases differ from solids.

187. *Effects of Heat.*—Although we cannot see the actual motion of the molecules of any body, which is the cause of its temperature, we can nevertheless detect the degree of this motion by the effect which it produces upon our senses, such as touch and sight, or the changes which it produces in the condition of other matter to which this heat motion is communicated. The sense of touch enables us by experience to tell whether there is a transfer of heat from the body to our hand, or whether the heat passes out from our hand into the body which we touch. In the former case, we speak of the body as *hot* or warm, and in the latter case as *cold.* It is, however, quite clear that this method of determining the temperature of a body can only be exercised within a very narrow range; and when a certain degree of heat or cold is reached, the hand, or any other part of the body, cannot detect the difference between heat and cold, because the transfer of heat to the body, or from it, becomes so great that the nerves of sense are destroyed.

We know this to be the case when the temperature of a body becomes so great that the undulations or motions produced in the surrounding ether become capable of affecting the nerves of the eye by the production of luminous rays, and we say the body is red hot or white hot when all ranges of luminous vibrations are produced In the same way, a very cold body will burn the flesh as well as a red hot body, but the transfer of heat is in the opposite direction.

When heat is communicated to matter which cannot feel, it undergoes certain changes. When a solid is heated, it continues to increase in volume up to a certain point, and then melts, or changes its state from a solid to a liquid. When the liquid is continually raised in temperature by the addition of fresh increments of heat, it undergoes an augmentation of volume until a certain point is reached, when it likewise assumes another condition, and passes into the state of a gas. The temperature at which the solid assumes the liquid condition is called the *melting point*, and the temperature at which the liquid passes into the gaseous state the *boiling point*.

When gases are permitted to cool, either by communicating their motion to the surrounding ether, or by other means for the abstraction of heat, they ultimately reach a point when the motion of the molecules becomes so reduced that the attraction of the molecules for each other causes them to fall together, and the gas becomes a liquid. This action we term *condensation*, of which we have the most familiar example in the formation of water by the condensation of steam. When a liquid is cooled, we at length reach a point when the motion of the molecules is so much reduced that their mutual attraction causes their oscillations to be arrested, and circumscribed about certain fixed centres, and the liquid becomes a solid. This point, in the case of water, is called the *freezing point*. These changes may be hastened or retarded by the degree of pressure to which the gases or liquids are subjected.

188. *Measurement of Temperature.*—We have already seen that it is quite impossible to determine differences of temperature in any two bodies, except within a certain narrow range, by the aid of the senses, and this is specially the case when exact quantitative determination of temperature is required. Indeed, the quantitative determination of temperature within any range by the unaided senses is almost impossible, because so much depends upon the condition of health. When we wish, therefore, to investigate the difference of temperature between any two different substances, or the temperature of any substance as referred to some fixed standard of temperature, we are obliged to have recourse to an instrument which is called a *thermometer*, or heat measurer. There are many kinds of thermometers, each of which has been designed for some special purpose in physical investigation, and depending upon several different principles in their construction; but they all agree in this respect, that the materials of which they are made receive heat from the surrounding bodies when they are hotter than the thermometer, and lose heat by communicating it to the surrounding bodies when they are colder, and thus are made to indicate on some suitable scale the amount of heat which they have gained or lost. The temperature of a body is therefore its thermal state, when considered in reference to its power to communicate heat to other bodies. When two bodies are brought into thermal communication, and neither gain nor lose heat, they are said to be in *thermal equilibrium*, or of equal temperature, and when two bodies in thermal communication gain or lose heat, then the body which loses heat is said to have *the higher* temperature, and the body which gains heat *the lower*. When two bodies have themselves the same temperature as a third body, they are said to be equal in temperature, because things which are equal to the same thing are equal to one another; and this is the foundation of the whole science of *Calorimetry*, or the measurement of temperatures. We may, however,

make this distinction: that those instruments which measure the quantity of heat are called *calorimeters*, while those which measure its intensity are termed *thermometers*.

189. *The Mercurial Thermometer.*—We have already seen that when any substance is heated it usually expands in volume, whether it is in the solid, liquid, or gaseous condition; and since within a certain range of temperature this expansion is constant for the same substance, and the same degree of difference in temperature, it affords a ready method of constructing a standard thermometer. A liquid is usually selected, because heat can more readily be communicated to every part of it by convection, and because, from the mobility of its molecules, the expansion can be concentrated into a narrow channel, and thus rendered more readily visible to the eye. Mercury has been specially selected for use in thermometers, because it does not boil till at a much higher temperature than water, or freeze until a much lower temperature. In the case of mercury the heat is communicated from molecule to molecule by conduction.

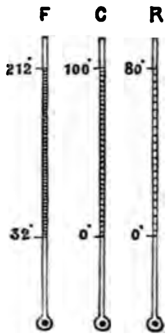


Fig. 69.—Thermometers.

The general construction of the thermometer will be readily understood by reference to Fig. 69. The instrument consists of a glass tube with a very narrow bore, and terminating in a thin glass bulb. This bulb is rather more than filled with mercury by suitable means, and then the mercury is heated in the bulb over a spirit-lamp until it boils, and the vapour fills the tube. When all the air in the tube has thus been expelled, the end of the tube at F, C, and R is hermetically sealed, so that when the tube is cooled down the mercury condenses and little more than fills the bulb, leaving a partial vacuum above. The instrument is then ready

for graduation. This is accomplished by dipping the bulb into a freezing mixture, consisting of pounded ice or half-melted snow, and the bulb containing the mercury contracts in volume, as does also the mercury within it, until the mercury sinks to a fixed point within the tube, and there remains stationary. This point is called the *freezing point*. The same thermometer is then placed in a suitable vessel, and surrounded by an atmosphere of steam at a pressure equal to the pressure of the air when the barometer stands 30 inches high. In this atmosphere of steam the mercury in the bulb of the thermometer expands, and rises up the tube until it reaches a fixed point, beyond which it will not rise. This point is then marked off, the same as the point at which the mercury stood when in the freezing mixture, and is called the *boiling point*. These two points are common to all mercurial thermometers, and are standard points, which can always be verified, because at the same atmospheric pressure water always freezes, and boils in the same vessel at an equal difference in temperature.

190. *Thermometric Scales.*—The interval between these two points has been divided into different numbers of parts, called *degrees*, in different countries. There are three common forms which are in general use in Europe, and which are called the *Fahrenheit*, the *Réaumur*, and the *Celsius* scales, from the names of the philosophers who first used them. The most scientific is the Celsius, which is also called the *Centigrade*, because the interval between the freezing and the boiling points is divided into 100 parts; the freezing point is marked 0°, and the boiling point 100°. Above and below these points, equal intervals are marked off within the whole range of the tube. The degrees below the 0° are called *minus* degrees, and are written – 1°, – 2°, and so on. This form of graduation is rapidly becoming almost universal in scientific researches, and will be seen at C in Fig. 69. In the Fahrenheit thermometer, marked F in Fig. 69, the interval between the freezing and boiling point is divided

into 180°, and the freezing point is marked 32°, because it was formerly supposed that at 32° below the freezing point of water was the greatest cold possible, and this point was therefore marked 0°, and called the *zero point*. The boiling point on this scale is therefore 212° above this zero point. This thermometer is in common use in England, and is convenient in some respects, because 1° on this scale corresponds within a reasonable range, say from the freezing point to the boiling point, to an expansion of $\frac{1}{10000}$th part of the volume of the mercury used.

The Réaumur scale, seen at R in Fig. 69, divides the interval between the freezing and boiling point into 80°, from 0° at the freezing point to 80° at the boiling point. This method of division is now seldom used, except in certain parts of the Continent of Europe, and is rapidly falling into disuse. The graduated divisions can either be marked on to the actual stem of the thermometer, or on to a scale fixed to it, and in many cases now the thermometer scale is graduated on one side of the stem into Centigrade degrees, and on the other into Fahrenheit degrees, so that either can be read with the same thermometer. It will be readily seen that equal divisions of the stem can only represent equal degrees of expansion when the bore of the tube is the same diameter in every part. Since this requirement can hardly ever be secured, it is necessary to compare all thermometers used for scientific purposes with a standard thermometer which has been carefully and accurately graduated, so that the errors may be known in every part of the stem. All thermometers are apt to vary from perfect correctness after continuous use, especially when the use has involved a great range of temperature, because the glass of which it is composed usually alters the capacity of the bulb permanently, and thus alters the scale.

When very low temperatures have to be measured, the mercurial thermometer cannot be used, because the mercury becomes solid, and therefore, for this purpose thermometers are constructed with alcohol in place of

mercury, and as this liquid when perfectly pure does not freeze with the lowest temperatures we can produce, it answers the purpose very well. Where very high temperatures have to be registered, mercury is equally inapplicable, and, indeed, glass cannot be used. The expansion of various solid bodies is then used to give the necessary indications, and these instruments are called *Pyrometers*.

191. *Expansion by Heat.*—Almost all bodies (there are a few exceptions), when they receive heat from any source, expand, and when they lose heat, contract, and this expansion or contraction takes place in every direction. For the same difference in temperature, solids expand the least and gases the most, while liquids occupy an intermediate position. For equal degrees of heat the same body usually undergoes the same extent of expansion within a fixed range of temperature, but different bodies, in all their states of solid, liquid, or gas, undergo very different degrees of expansion. In liquids and gases the expansion always takes place equally in every direction, when the molecules composing them are free to move equally in every direction; but in solids this is not always the case. The expansion of a solid in length is called *linear* expansion, and in volume, *cubical* expansion. If we take a metal bar which will just fit in between two fixed points, which serve as a gauge, and then warm it, we shall find that the linear expansion prevents it with the increased temperature from passing within the gauge; and if we take a metal ball which will just pass through a round hole in a metallic plate, and warm it, we shall find that its cubical expansion will then prevent its passage until cooled down to the original temperature. The fixed amount which any substance expands in terms of its length or volume, when subjected to a heat which will raise its temperature 1°, is called the linear, or cubical, *co-efficient of expansion* of that substance.

192. *Expansion of Solids.*—Under the influence of heat, solid bodies vary very much in the degree of

expansion, both linear and cubical, which they undergo. Amongst metals, zinc is one of the most expansible, and platinum the least. The expansion of platinum and glass is very nearly the same, and hence, platinum can be fused into glass, which is a great advantage in the formation of many electrical and other instruments, without the glass being liable to fracture. The force of expansion or contraction under the influence of heat or cold in solid bodies is very great. A heated bar of metal, when cooling, will exert a very great pressure on any points with which it is rigidly connected when in the heated state, and this force has sometimes been used to draw in the sides of buildings which have been bulged out, by heating the tie-rods, screwing them up when hot, and then allowing them to cool, and so become shorter. In the same way, water when freezing into ice, and which at that temperature is an exception to the rule of expansion, because it increases in volume from about 40° Fahr. down to 32° Fahr., instead of contracting, exerts such a pressure upon the walls of any vessel which it just fills at the former temperature, that when changing into ice it will burst even a thick iron shell. The bursting of water-pipes in dwelling-houses, which causes such inconvenience in severe frost, is an example of this great power of expansion. As a rule, amongst ordinary solids the co-efficient of cubical expansion is three times the linear co-efficient. The difference in the expansion of different bodies under equal increments of heat has been turned to very useful account in many applications in the arts and sciences. One of the most useful is the compensation pendulum in clocks and the balance-wheel of watches and chronometers. We have already seen that the vibrations of a pendulum decrease in number as the length increases, and hence, with an uncompensated pendulum the clock which it regulates will gain time in winter, and lose it in summer; because being colder in winter the pendulum is shorter, and warmer in summer the pendulum is longer. By forming the pendulum

of rods of different metals, so that the difference in their expansion always keeps the point of suspension at the same distance from the centre of gravity of the pendulum, the number of vibrations is rendered constant. In the same way, the rim of the balance-wheel in the chronometer is formed of a compound bar or bars, which cause the weight of the rim to advance or recede from the centre with changes of temperature, and thus regulate the number of oscillations which it will make, and by this means the speed is regulated. Sometimes the pendulum weight is formed of a vessel containing a quantity of mercury, arranged so that when the heat expands the rod of the pendulum, and so lengthens it, it also expands the mercury, and causes it to rise in the vessel, and thus alter the centre of gravity upwards, to counteract the increased length of the rod.

193. *Expansion of Liquids.*—Liquids, like solids, vary very much in the expansion which they undergo when subjected to the same increase in sensible temperature, as indicated by the thermometer. The fraction of the total volume of any liquid which it expands when increased 1° in temperature is called, as in the case of solids, the *co-efficient of expansion* of that liquid, and with few exceptions, and within very narrow limits of the freezing and boiling points, is always a constant quantity for the same liquid when under the same conditions of pressure. As we have already seen, the structure of the mercurial and other liquid thermometers depends upon this law. The expansion of liquids is not, however, perfectly uniform, and this irregularity becomes very great when the boiling point is nearly reached.

Water presents a very remarkable exception to the general law that between the freezing and boiling points the volume continues to increase by the addition of increments of heat. Water, as we have already seen, freezes at 32° Fahr., and if we warm it until it registers 39.4° Fahr., or very nearly 40° Fahr., we find that, instead of expanding, it continuously contracts until the latter

temperature is reached. At this point the water has the *greatest density*, and therefore any given volume of water weighs more at this temperature than at any other. If we continue to add further heat, we find from this point that it commences to expand, and then follows the ordinary law of liquid expansion up to nearly the boiling point, 212° Fahr. This fact has an important bearing in the economy of nature, for it secures that water shall always commence to freeze at the surface of a lake or river rather than at the bottom, because the water never begins to freeze until the whole has been cooled down to 40°, and then the ice forming at the top prevents the lowering of the temperature in the water beneath, except by conduction. Fish can therefore live beneath the surface of the ice, and not be subjected to a lower temperature than about 40° Fahr.

194. *Melting Point.*—Most solid bodies, when subjected to a continuous increase in temperature, continue to expand until a point is reached at which the solid state can no longer be maintained, and the body assumes a liquid condition. This melting point differs in almost all cases for different substances, but remains constant for the same body. Some substances, such as wood or stone, do not melt, but become decomposed or chemically changed, while carbon itself neither changes nor melts, however high the temperature, even when increased to a white heat. Hence the use of carbon to form the poles in an electric arc or the thin filament in an incandescent lamp. The behaviour of different bodies just at the melting point under the influence of temperature varies very much, and some pass suddenly from the one state to the other, while others have an intermediate stage of viscosity, like softened glass or wax, which can be moulded into any desired form. The difference in the melting point of different solids is very great. Phosphorus, for example, melts at about 80° Fahr., which is far under the boiling point of water, while platinum only melts at about 3,600° Fahr. When passing from the

solid to the liquid condition, almost all substances change in the volume which they occupy. Water, for example, when obtained from ice, occupies less volume than the ice from which it was produced, and many other substances act in the same way. It has been found that all bodies which contract in this way when passing from the solid to the liquid condition have their melting point lowered when subjected to greater external pressure, and the reverse takes place when the substance expands on liquefaction, which is the case with such substances as wax or sulphur. These phenomena are in strict accordance with the requirements of the mechanical theory of heat.

195. *Boiling Point.*—When a liquid is heated up to a certain point, which is constant for the same liquid under the same conditions of pressure, but different for nearly all substances, the liquid condition can no longer be maintained, and it passes into the gaseous state. This boiling point is so low in some liquids, such as ether, that it is below the ordinary temperature of the human body; and we are all familiar with those fixed gaseous bodies, such as oxygen and nitrogen, in the air which can only be retained in the liquid condition by the application of intense pressure and cold. The influence of pressure upon the boiling point has already been noticed, and hence, in measuring the temperature at which any liquid boils, it is always necessary that the pressure should be noted, and be the same when comparison with other liquids is desired. The boiling point of any liquid, indeed, is always that point at which the elastic force of the vapour exactly overcomes the pressure which is above it, and the molecules of which the liquid is composed therefore pass into the superincumbent atmosphere. Under pressure, the boiling point may be raised to a point far above that at which the liquid boils under the ordinary atmospheric conditions. In the case of water, the rise amounts to about $\frac{1}{6}$th of a degree Fahr. for every $\frac{1}{10}$th of an inch of rise in the barometer, and

falls in a corresponding degree with a fall in the barometer. Hence, water boils at the top of a mountain or under the receiver of an air-pump at a far lower temperature than 212° Fahr. The fall in temperature is about 1° Fahr. for every 590 feet of elevation; and hence, if we note the boiling point of water at two different stations, we can approximately estimate the difference in the elevation of the two stations.

196. *Expansion of Gases.*—From the nature of the conditions of the molecules in any gas, the process of expansion or contraction under the influence of higher or lower temperature does not take place in the same manner as in solids or liquids. When the gas contained in any given space is cooled, it does not cease to occupy the same space, but its elasticity is decreased, and it ceases to exert the same pressure which it formerly did upon the walls of the containing vessel. When the temperature is increased the elasticity is also increased, and the pressure upon the walls of the vessel also increased. If the pressure is maintained constant, by permitting the gas to expand and fill a larger volume, and therefore exert the same pressure upon the walls of the containing vessel, it is found that within certain limits all gases expand in exactly the same proportion of their original volume for every similar increase in sensible temperature. This co-efficient of expansion may be taken at $\frac{1}{490}$th of the original volume of the gas for every 1° Fahr. which it is increased in sensible temperature, and the elasticity of the gas, or the pressure which it exerts upon every square inch of the containing vessel, if the volume is kept constant, is also augmented in the same degree by the same rise in temperature. In speaking of the various scales in use for the graduation of thermometers, we have already seen that in the case of the Centigrade and Réaumur the freezing point of water at the ordinary atmospheric pressure is taken as the zero, or starting point from which the degrees are measured. In the Fahrenheit scale the zero is 32° below this point. The constant co-efficient of ex-

pansion of gases, however, gives us a much more scientific zero point from which to measure temperatures, and which enables us to simplify the expression of the two laws of Boyle and Charles, which we have already seen (133, 134), into one general law, viz.: that the product of the volume and pressure of any gas is proportional to the absolute temperature when measured from the *absolute zero*. If the increase of 1° Fahr. increases the elasticity or volume of any gas by $\frac{1}{490}$th part of the original volume, then the cooling of the mass by the same degree will decrease the volume or elasticity by the same amount; and hence when, say, at the temperature of freezing water (32° Fahr.), we decrease the temperature 490° Fahr., or to about 458° below the zero of Fahrenheit, we shall reach the point where all the elasticity and temperature of the body will be exhausted, and this point—458° Fahr.—is termed the *absolute zero*. At this point, according to the dynamical theory of heat, all the motion of the molecules of the body, upon which its sensible temperature depends, would cease, and we should probably have a condition of things which would present as great a difference between the condition of matter in that state as between the present phenomena exhibited by solids, or liquids, and gases, and which we may term an *ultra-solid state*. No means at our command enable this temperature to be produced, and hence there may be a failure in the law of decrease in elasticity in its relation to temperature before we reach the absolute zero; but the law holds good within all the range of experimental observation.

197. *Specific Heat.*—We may here mention that, except under the same conditions of pressure, and within a comparatively narrow range of temperature, the same quantity of heat will not raise the body through the same number of degrees of sensible temperature. Thus, it requires a different amount of heat to raise the temperature of a given volume of water from 39° Fahr. to 40° Fahr., or through 1° Fahr., than it does to raise the

P

same volume from 100° Fahr. to 101° Fahr., or through 1° Fahr. in a different part of the thermometric scale. The capacity to receive heat in any substance is called the *specific heat* of the body, and it differs in nearly every substance, in the gaseous, liquid, and solid condition. Not only so, but it differs for the same substance at different temperatures, except in the case of perfect gases, when the specific heat of a given mass of the same substance remains constant within all known ranges of temperature. The specific heat of water is thirty times greater than that of lead, so that the same quantity of heat which would raise 1 lb. of water through 1° Fahr. in temperature would raise 1 lb. of lead through 30° Fahr. In the same way, the specific heat of air is only about one-quarter that of water; and since air is about 770 times lighter than water, the same quantity of heat which would raise a cubic foot of water through 1° Fahr. would raise the whole volume of air in a small room to a red heat. This accounts for the very great influence of the ocean upon climate, as the water absorbs such large quantities of heat that it exercises a cooling influence in summer, and the heat given off in winter warms the air to a far larger degree than would be the case if the specific heat of air and water were the same. As regards gases, the specific heat is greater when the volume is kept constant than when the pressure is constant, because in the latter case expansion takes place, and a larger amount of heat is absorbed in the performance of intermolecular work, on account of the increase in volume. In a perfect gas this relation is as 1 to 1·414.

198. *Latent Heat.*—When any body passes from the solid to the liquid or gaseous condition, a considerable quantity of heat is absorbed, which becomes *latent*, so that it does not affect the sensible temperature of the body. Thus, when ice is melting in water, which is supplied with a continuous number of increments of heat, the temperature of the water never rises, notwith-

standing the continuous supply of heat, so long as the least quantity of ice remains unmelted. In the same way notwithstanding the continuous supply of heat, when we reach the boiling-point the temperature of the water never rises above 212° Fahr. so long as any water remains; and the temperature of the escaping steam is also only 212° Fahr. In consequence of a portion of the heat becoming latent in the melting of ice, it follows that to melt any quantity of ice as much heat has to be imparted to it to enable it to melt as would raise the same weight of water 143° Fahr., and the temperature of the melted ice will only be the same sensibly as that of the solid ice. In the same way, to convert any weight of water at a temperature of 212° Fahr. into the same weight of steam at the same temperature requires 967 times as much heat as would raise the same weight of water through 1° in temperature. Hence, we say the latent heat of water is 143° Fahr., and of steam 967° Fahr. When the water freezes into ice, or the steam condenses, the whole of this latent heat re-appears again. Latent heat may thus be defined as the quantity of heat which must be communicated to any body in a given state in order to change it into another state without any alteration in the sensible temperature of the mass. According to the dynamical theory of heat, this latent heat is entirely employed in forcing and keeping asunder the molecules of the water which, in the case of steam, is rendered visible by the greater volume which it occupies as compared with the water. The heat is, indeed, employed in conferring upon the molecules of the water greater potential energy, which is released and becomes kinetic when the steam condenses or the ice melts. It is in consequence of this latent heat that steam will scald the body more than hot water at the same temperature, and that a fall of rain or snow warms the atmosphere.

199. *Convection of Heat.*—When liquids or gases are heated at any point, the heat is distributed throughout

the whole mass of the liquid or gas by the formation of currents within the mass. These currents are the results of the greater motion imparted to some of the molecules of the body by the application of the heat, and being free to move, they force their way amongst the colder molecules, and thus tend to equalise the temperature. When heat is applied at the bottom of any vessel, the molecules of liquid or gas tend to expand farther apart, and thus become relatively lighter by occupying a larger volume, and under the action of gravitation they rise upward. This upward current also produces a corresponding downward current, because as the one set of molecules rises the colder molecules rush in beneath them, and thus come in contact with the source of heat. If heat were applied at the top of the vessel instead of at the bottom, then no currents would be formed, because the expanded molecules would remain at the top, and have no tendency to distribute themselves through the mass except by the slow process of transfusion. The currents of the ocean, such as the Gulf Stream, are the result of this convective action of the warm waters of the tropical seas, and the winds are the result of the unequal heating of the air by the sun and contact with unequally heated portions of the earth.

200. *Conduction of Heat.*—When the molecules of a solid body are heated in any part, they are not free to move in the same way as those of a liquid or gas, and hence, no currents are formed. The heat is, however, slowly communicated from molecule to molecule by the increased motion of the heated molecules being communicated to those which lie next to them. This process of communicating heat is called *conduction*. We have a good instance of this method of the transference of heat when a silver spoon is placed in a cup of hot liquid. The heat is slowly communicated up the stem of the spoon, until, if the liquid be sufficiently hot, it is impossible to touch the end of the spoon without burning the fingers. Solids differ very much in the capacity which

they possess to conduct heat. Metals possess it in the highest degree, although they differ very much in this respect. Such substances as glass or wood, and fibres or textile fabrics of wool or cotton, are very bad conductors. In consequence of this latter property, we clothe ourselves in cotton or wool, because they will not conduct the heat away from the body, but cause it to be retained, and hence they afford the necessary protection against radiation, or the cooling influence of the surrounding air. This is the reason why when we touch a piece of cloth it feels warm, because it does not conduct the heat away from the fingers; but if we touch a metal plate it feels cold, as the heat is abstracted from the hand and conducted into the interior of the metal. If a series of thermometers be inserted into a metallic bar, at different distances from the end, and then heat be applied at the end, it will be found that the thermometer nearest the end is affected first, then the next, and so on to the last. The rise in temperature will also be greatest always in the thermometer nearest to the source of heat, and it will diminish as we recede from it. Amongst metals, silver possesses the highest degree of conductivity, and platinum amongst the least, while copper, gold, iron, and lead occupy intermediate positions, in the order in which they have been here named.

201. *Radiation of Heat.*—When the hand or any other portion of the body is placed at a distance from any heated substance, a sensation of warmth is experienced, in consequence of the radiation of heat from the surface of the hot substance into the surrounding space. This arises from the fact that the motions of the molecules of the heated substance, which constitute its sensible heat, are communicated to the surrounding ether, which pervades all space, and these ethereal motions are the radiant heat. In the same way, when they reach a certain degree of intensity they become visible as light. We have already seen (179) that when the rays of energy which emanate from the sun are dispersed by

means of a prism, we have, in addition to the luminous rays, which are arranged in a certain definite order, a heat spectrum beyond the extreme red and a chemical or actinic spectrum beyond the extreme violet, and that there is every reason to suppose that the heat and actinic rays differ from the luminous rays only in the length of the ethereal wave which constitutes them. This identity in kind between heat and light and actinism is further proved by the fact that heat and actinism, like light, are capable both of reflection and refraction from the surface and through the substance of various bodies. During reflection and refraction radiant heat obeys exactly the same laws as light, and it is unnecessary, therefore, to repeat them here. Heat can also be made to undergo polarization, both plane, circular, and elliptical, exactly the same as light, and the heat-waves can also be made to interfere with each other, and produce phenomena which are strictly analogous to the same results obtained by luminous rays. The velocity of radiant heat in traversing space is also very similar to that of light.

202. *Absorption of Heat.*—The power which different substances possess to absorb radiant heat differs very widely. This power depends upon the capacity of the molecules of which the substance is composed to receive motion from the ethereal waves which break upon them. It has been found that all those bodies which, when heated, can readily communicate the motion of their molecules to the surrounding ether, can with equal facility have their molecules set in motion by the ethereal waves, and hence, all good radiators possess great power of absorption, and all bad radiators have an equally small power of absorption. Amongst gases, water-vapour possesses this power in a very remarkable degree The aqueous vapour of the air exerts an absorbing influence about seventy times greater than that of the air itself, and hence a very thin stratum of moist air will prevent the radiation of heat from the earth into space far better than a much thicker stratum of air. The aqueous

vapour in the air thus plays a very important part in the economy of nature, because it prevents the escape of the heat from the earth into space which would otherwise enormously increase the difference in temperature between night and day. Indeed, if all the aqueous vapour were removed out of the atmosphere, it is highly probable that the unrequited radiation into space for a single night would reduce the temperature of the earth's surface to a point far below that at which life could possibly be sustained.

203. *Transmission of Radiant Heat.*—We have already seen that many substances possess the property of transparency in regard to luminous vibrations, and that a very great diversity exists amongst these bodies in regard to the degree of transparency—some substances transmitting nearly all the light, while others intercept a large quantity. In the same way, many substances possess the property of transparency to heat vibrations or radiant heat. This property of substances is called *diathermancy.* Although both light and heat are vibrations of the same ethereal medium, it is found that transparent substances are by no means all diathermanous. Rock salt, however, which is partially transparent, is very highly diathermanous, and seems to allow free transmission to heat-waves of all wave-lengths, and hence, can be formed into prisms and lenses, which will disperse or concentrate rays of heat, in the same way that glass prisms and lenses disperse and concentrate light.

Liquids and gases also differ very much in regard to their power to transmit heat rays, and some which are quite transparent to light are impervious to heat; while others, which are opaque to light, are highly diathermanous. As a rule, the substances which possess the most simple atomic structure are the most diathermanous, especially when in the gaseous state. The nature of the source whence the radiant heat is derived is also important, because many bodies which are comparatively diathermanous to the most refrangible heat rays are quite impervious to those which are less refrangible.

204. *Heat and Work.*—We have already seen that whenever heat is expended in expanding the volume of any substance, a certain amount of work is done by forcing asunder the molecules of the body, and thus storing up the energy in a potential state. In the case of a gas which is confined within a vessel which prevents its expansion, the work accomplished by heating it increases the molecular motion of the gas, and thus augments its elasticity, which is measured by the increased pressure on the walls of the vessel. This increased elasticity may be utilised by permitting the gas to expand behind a movable piston, as in the cylinder of a steam-engine, and the result is the performance of mechanical work. In the same way, when mechanical energy is expended in the compression of bodies or in friction, we have a considerable amount of heat produced. This may easily be shown by the sudden compression of a tight piston which will heat the air enclosed in the cylinder, or it may be observed in the stream of fire which flies from beneath the wheels of a train arrested by the sudden application of the brake. The reduction of the laws according to which these phenomena take place to a physical theory constitutes what is called the science of *thermo-dynamics.*

205. *Thermo-dynamics.*—The relation which subsists between the quantity of heat units which are expended in the performance of mechanical work and the quantity of work accomplished when measured by the weight which can be raised against a constant force, such as gravitation, is always a constant quantity. From a very large number of experiments which have been made in various ways to determine what is the numerical relation existing between heat and work, we may select the one employed by Dr. Joule as the most easily understood. Fig. 70 shows the apparatus, where B is a copper vessel enclosing a paddle, which can be revolved by the descent of a weight, which unwinds a cord round the axis, A. When the weight has reached the bottom, the

pin, P, is taken out, and the weight again raised by the revolution of the handle at the top of the axis. The pin is then replaced, and the weight allowed to fall again. The height through which it falls is measured on a vertical scale. Inside the copper vessel are a series of partitions, through which the vanes of the paddle pass, and thus prevent the rotation of the water, and thus the

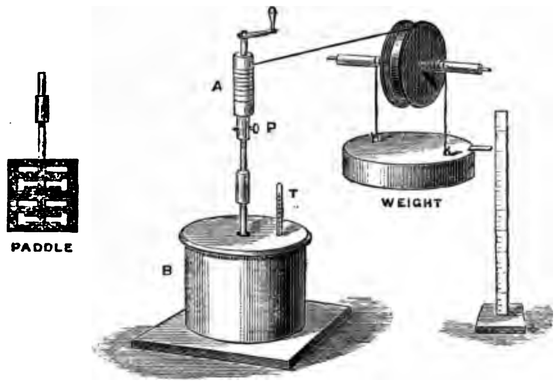


Fig. 70.—Apparatus for Determination of the Mechanical Equivalent of Heat.

whole energy of the falling weight is employed in warming the water by the friction of the paddle amongst the molecules of the water. The degree to which the water is warmed by any required fall of the weight is read off on the thermometer, T. By this means Joule established the general law, which constitutes the first law of thermodynamics: viz., that the fall of 772 lbs. through 1 foot will exactly raise 1 lb. of water 1° Fahr. in temperature; or the converse: that the same amount of heat which will warm 1 lb. of water 1° Fahr. in temperature will, if entirely expended in the performance of mechanical work, raise 772 lbs. 1 foot high against the force of

gravity. This quantity is known as the *mechanical equivalent of heat*, and its discovery will always form one of the great epochs in the history of science. The second law of thermo-dynamics may be stated as follows:—If the absolute temperature of any uniformly hot substance be divided into any number of equal parts, the effects of each of those parts in causing work to be performed are equal. The relationship, therefore, between heat and work is a fixed and invariable quantity, and however the heat may be expended, it can never perform more or less than a constant amount of mechanical work. In the same way, however mechanical energy may be expended in the production of heat, it can only produce a certain and invariable quantity of absolute heat. As a result of this, the total quantity of work which any heat engine can perform will always be measured by the difference in absolute temperature between that at which it receives the steam, hot air, or other source of energy, and the temperature at which it parts with it.

CHAPTER III.

ELECTRICITY.

I. FRICTIONAL ELECTRICITY.

206. *Nature of Electricity.*—Nothing is known respecting the real nature of electricity, but it is in all probability a form of energy which is intimately associated with matter, in some such way that its manifestations are the result of the reaction of the ethereal medium and the molecules of matter upon each other. Electrical manifestations are always of two opposite characters, and have been named *positive* and *negative*. Since they always appear and disappear simultaneously, they must, however, be regarded as parts of the same phenomenon,

and in their nature *one*, not *two*. These two opposite kinds of electricity are each self-repulsive, but mutually attractive; so that a body positively electrified repels any other body in the same condition, but attracts any body negatively electrified; and a negatively electrified body repels negative bodies, and attracts positive ones. Electricity is not rare, but one of the commonest phenomena of the world, and pervades every manifestation of matter which is presented by the changing conditions in which matter is exhibited under the action of force. Hence, electrical phenomena accompany every mechanical and chemical change occurring in matter, and is so intimately connected with them that they cannot be regarded as isolated phenomena, but only parts of a vast series of effects due to an imponderable medium, in which and by which matter itself probably exists, and on which all modes of force, such as light, heat, electricity, and even gravitation, probably depend.

In the study of electrical phenomena it is necessary to suppose that all bodies are charged with a neutral imponderable fluid, which is decomposed into two imponderable fluids, called positive and negative electricity, whenever electricity is made manifest. These two electricities are always equal in quantity, and when permitted to combine together, re-form the neutral fluid again, when the evidence of electricity disappears. We must not understand that either of these fluids have any real existence, but the terms used in describing material fluids enable us to picture to the mind and assist in the explanation of the electrical properties of matter.

Every substance around us is in a different electrical condition from all other substances with which it is in contact.

Electricity, indeed, seems rather to partake of the nature of a strain in certain definite directions, which is induced in the electrified body, and which is propagated in different directions unequally, and also with a

different velocity in different bodies. Whenever the nature of a body is such that it permits this strain to pass through its substance, it is called a *conductor*, and whenever it resists the passage, an *insulator*. All bodies possess both these properties to a greater or less degree, so that the difference between various bodies in this respect is only one of degree—none are perfect conductors, and none perfect insulators.

207. *Production of Electricity.*—Although all different bodies are in different electrical states, yet under ordinary conditions this difference is so slight that it cannot be detected by unaided senses. When, however, two insulators are rubbed together, or brought into close contact, the difference in electrical condition is rendered so great that the one becomes charged with positive and the other with negative electricity. Upon this principle electrical machines are usually constructed. The simplest electrical machine consists of *a glass rod* held in the hand, and rubbed with a warm dry *silk cloth*; and if this rod is then presented to a pith ball, suspended by means of a silk thread from a glass support, as in Fig. 71, we shall find that the ball is first attracted, and then, after touching, repelled. If we move the rod nearer to the ball, it will then move away from it, showing that it is in a state of permanent repulsion. If now we take a *rod of sealing-wax*, and after rubbing it with *flannel*, present it to the ball, we shall find the ball is first attracted, and then repelled. It will now again be attracted by the glass rod, and then repelled from it. This arises from the fact that the electricity produced by the friction of the glass and silk

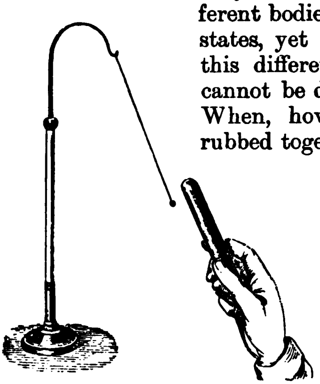


Fig 71.—Electrical Pendulum.

is of the opposite kind from that produced by the friction of wax and flannel. The electricity of glass is called *positive*, and of wax or resin *negative*.

In consequence of the pith ball being suspended by an insulating thread, which will not permit the electricity communicated to it to pass, it retains the condition of electrical excitement produced in it by contact with the glass or wax rod. When, therefore, the glass rod is presented to the ball, the neutral fluid in the pith ball is decomposed by the positive electricity of the rod, and the positive electricity on the ball being repelled away to the opposite side of the ball from the rod, the ball is attracted to the rod, because it is in the opposite electrical state on the side nearest the rod; but when it has once touched the rod its electricity is neutralised by that of the rod, and then charged with the same electricity and repelled. Although repelled by the glass rod, it will now be attracted by the wax rod, and then repelled from it. If the glass and wax rod be held on each side of the suspended ball, it will pass from one to the other alternately, till all the electrical excitement on the rods has passed away, being alternately attracted and repelled from each rod respectively. The electrical *charge*, as we term the accumulation of electricity on the two rods, is thus communicated by means of contact with the pith ball. Contact is not, however, the only way in which bodies communicate electricity to each other, because when the charge is great the passage of a *spark* or flash between them without contact will communicate the electricity of one to the other. In this way the electricity of the earth and clouds is communicated to each other in a thunderstorm in the form of lightning.

Whenever, indeed, an electrified body is brought near to a non-electrified conductor, the electricity of the latter is decomposed, and one of its constituents repelled, while the other is attracted. This decomposition of the electric fluid by the presence at a distance of an electrified body is called *induction*. Although friction is usually con-

sidered the cause of electricity, it is certainly not so in the same sense that it is the cause of heat, because the amount of electricity produced, as measured by the *work* which it will do, bears no relation to the amount of friction. It is probable, indeed, that the only essential condition for the production of electricity is contact between dissimilar bodies.

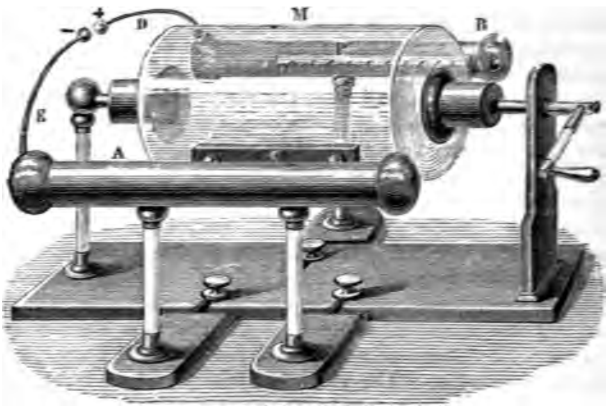


Fig. 72. - Electrical Machine.

208. *Electrical Machines.*—When powerful charges of electricity are required, it is necessary to employ mechanical means to produce the friction between the two exciting bodies. Fig. 72 gives a good illustration of one of the commonest forms of electrical machine. A cylinder of glass, M, is fixed on a horizontal axis, so that it can be rotated by means of a handle. This axis is insulated from the tube on which it rests by glass rods, which are remarkably bad conductors of electricity. A hollow brass tube, A, carries an elastic cushion, C, the surface of which is coated with an amalgam of zinc or tin, and presses against the glass cylinder.

This cushion is supported also on glass rods, placed a short distance behind the cylinder. A silk cloth is usually attached to the cushion and passed over the upper surface of the cylinder, and lies upon the top of it. In front of the cylinder a hollow brass tube, B, corresponding to A, is placed, having a number of points, P, like the teeth of a comb, projecting out behind towards the cylinder, but not touching it. The tube B is called the *prime conductor*. When the cylinder is rotated in the direction from A to B, the friction of the glass against the cushion and the silk cloth produces positive electricity on the surface of the cylinder, which passes through the points of the comb-like projections to the prime conductor, B, and accumulates on this surface. The negative electricity remains on the cushion and silk cloth, and is accumulated on the conductor A. When two bent rods, E and D, are inserted in the ends of the two conductors, and brought near together, a brilliant spark will pass between the two balls in which they terminate. The spark is not electricity, but incandescent matter, which is disrupted from the end of the conductor by the energy of the discharge, and carried across the intervening space, and hence the colour is modified by the nature of the conductor. These two points are called the *poles* of the machine. Under ordinary circumstances the negative conductor is connected by a chain with the ground, so that the negative electricity escapes away, and the positive electricity can be used for experimental purposes; but by insulating the negative conductor, and connecting the positive with the ground, the negative can be collected and used also. It is usual to express the positive electricity by the sign +, and negative by the sign −.

In the machine above described the rubbed surface is a cylinder of glass, hence it is called a *cylinder* machine; but other forms are employed, such as where a circular glass plate is used, and both sides are rubbed by elastic cushions. These are termed *plate machines*,

and are more powerful than cylinder machines, but less compact. There are also machines constructed the action of which depends upon the inductive action of a fixed charge of electricity, which produces the opposite electricity on a portion of the machine which is being continually discharged.

The *Electrophorus* is a simple machine of this nature, in which a circular plate of ebonite or resin is charged with electricity by rubbing. A smaller disc of metal or wood covered with tin-foil, and having an insulating glass handle in the centre, is then placed on to the ebonite disc, and touched with the finger, so as to allow the electricity on the upper surface to escape. When the small disc, which is called the *cover*, is raised by the handle, it is found to be powerfully charged with the opposite electricity to the ebonite plate. This operation can be repeated as often as required, by discharging the cover and replacing it again, and thus a continuous supply of electricity be generated by the original charge on the ebonite plate. In addition to these, we have also a machine which produces electricity by the disengagement of aqueous vapour through narrow orifices, and which is called a *hydro-electric* machine. Various modifications have been introduced into all these machines, which have greatly increased their efficiency, but which we have not space here to describe.

209. *Leyden Jar.*—When it is necessary to accumulate large charges of electricity, an arrangement is employed called a *Leyden Jar.* Fig. 73 gives an illustration of this jar, which is coated outside and inside with tin-foil up to within a certain distance from the neck. The top of the jar is stopped with a wooden lid, through which a brass rod with a ball at the top passes, and which, by means of a short chain, is placed in metallic communication with the inner tin-foil coating of the jar. When it is required to charge the jar with electricity, the outside coating is brought into connection with the earth, by placing it upon some

conducting substance or holding it in the hand, and the ball communicating with the inside is presented to the prime conductor of a machine, or other source of electricity. The + electricity thus becomes accumulated on the inner surface of the jar, and – electricity on the outer surface; and this accumulation may be continued until the *tension*, or tendency to unite, becomes so great that the electricity will spring across a considerable interval, when the two surfaces, inside and outside, are connected together, either by a wire from the ball to the surface of the outer coating, or in any other way. If the connection be made by means of the human body, by holding the jar with one hand on the outer coating, and touching the ball with the other hand, a very smart shock will be experienced. When very large charges are required, it is usual to connect together a number of these jars, by placing them upon a conducting substance, and then placing the balls in metallic communication. This combination is called a *Leyden Battery*. The shock from a powerful battery of this description is sufficient to destroy life, and a spark several inches in length will pass between the poles when connection is made. The charge which any Leyden jar can hold depends upon the extent of the coated surface, and for small thicknesses of glass is inversely proportional to the thickness, so that large and thin jars hold the most powerful charges.

Fig. 73.—Leyden Jar.

210. *Electrical Charges.*—Although, as we have already seen (206), we know nothing of the real nature of electricity, we can treat an electric charge as a measurable quantity, by making observations on the force

due to the charge. Bodies charged with the same electricity repel each other, and with opposite electricity attract each other; and it has been found that equal charges under equal conditions always produce equal forces. A unit quantity of electricity is taken, which may be defined as that which repels another equal quantity at unit distance with unit force; and it is always found that when two such units of opposite electricities are united, they neutralise each other, and when two of the same sign are united, they exert a double force under the same conditions. Instruments which are used to indicate the existence of electric charges are called *electroscopes*, but when they are arranged so as to indicate numerical differences, they are called *electrometers.*

211. *Distribution of Electricity.*—When electrical separation has taken place, the distribution of electricity at rest on any conductor is such that the force between any indefinitely small quantity of electricity and every other quantity varies inversely as the square of the distance between them; and this force is one of attraction between electricities of different kinds, and repulsion between electricities of the same kind. In consequence of this law, when any electrical charge is imparted to a conductor, it will, when at rest, lie upon the surface of the conductor, although it may pass through the body of the conductor when in a state of motion; and when any conductor forms a closed shell or hollow sphere, which contains an insulator inside, such as air, the electric charge will be entirely upon the external surface. The nature of the surface, however, modifies considerably the density of the charge which is upon it, because the electricity accumulates in the larger quantities on all the ridges and points than upon flat or rounded surfaces with large curves. This unequal distribution renders the escape of the electricity into the surrounding space greater from corners and points than from flat surfaces; and in the same way, points attract electricity better than level

or gently-rounded surfaces. Hence the use of pointed terminals at the end of our lightning conductors.

212. *Electric Potential.*—When electricity is in motion upon the surface of any conductor, before a condition of electric equilibrium has been established, the tendency which any portion of the electricity upon the conductor possesses in virtue of which it moves from any one position to any other, is called the *electric potential*, and the arbitrary standard which is selected, by means of which we measure the relations of the potential of any body, is the force with which it will pass from the body to the earth, as determined by the work which it can perform during the passage. The potential of any conductor or point is therefore only the difference between its potential and that of the earth, in the same way as the work which any head of water or other gravitating matter will do depends upon the height above the sea level. The total quantity of work which can be performed by the passage of any given quantity of electricity, from a higher to a lower potential, is always the same for the same difference of potential; and hence, electrical separation follows the same invariable law as other forms of energy, and the relation between expenditure of power and work performed is constant when measured by a standard unit.

213. *Velocity of Electricity.*—When work is performed by the passage of electricity from a higher to a lower potential, time is occupied in its performance; and the length of time depends upon the difference in potential between the two points, and the resistance offered to the passage of the electricity. When the motion is along a conducting body, such as a metal wire, we term the moving electricity a *current* of electricity. Thus, when the outer and inner coating of a charged Leyden jar are connected together, a current passes between them. Since the two coats are in opposite electrical conditions, an equal and opposite current starts from each end of the conducting wire, and the middle of the wire is last reached by the current. In practice, however, it is usual

only to consider the + current, and the direction in which this moves is called the *direction* of the current. The velocity of the propagation of electricity has never been exactly determined, because for a given quantity it depends upon the capacity of the conductor; but with a copper wire, and the discharge of a Leyden jar, Wheatstone calculated it was about 288,000 miles per second, which far exceeds the velocity of light. Electrical induction, which acts across the interval between an electrified and a non-electrified body, also occupies time—a time which differs in length with almost every different substance. In the case of air, the velocity of electro-magnetic induction is practically the same as that of light in air, or about 186,000 miles per second—a fact which evidently indicates a high probability that the two manifestations are different modes of motion of the same medium.

II. VOLTAIC OR GALVANIC ELECTRICITY.

214. *Voltaic Pair.*—When a plate of zinc and a plate of copper—or, indeed, any two dissimilar metals—are partially immersed in a vessel containing weak acid which dissolves one of the metals, the free end of the zinc plate assumes a – condition, and the free end of the copper plate a + condition. If these two free ends are united by a wire, a current of electricity flows from the + to the – pole. Of course, as in the case of frictional electricity, a current of equal intensity also flows in the opposite direction, but we usually only consider the + current. During the passage of the current a change also occurs in the liquid between the plates, which undergoes decomposition, hydrogen being liberated at the surface of the copper plate, while the zinc is oxidised, and dissolves in the liquid. No change, however, is visible in the liquid between the two plates, the action taking place only at the surface of the plates. The liquid in any voltaic cell is termed the *electrolyte*, and the act of decomposing any liquid by means of an electric current *electrolysis.* Beneath the surface of the electrolyte the two plates are in the

opposite condition to what they are above. The zinc is in a + state, and the copper in a – state. The zinc is therefore called the *positive element*, because it is in a + condition, but the end of the wire from the upper part of the zinc plate is called the – pole, and the copper plate is called the *negative element;* but the wire from the copper plate terminates in the + pole. When any two metals are used in the plates, it is always found that the two plates assume opposite electrical conditions, and the various elementary substances may be arranged in the order in which they are electrically related to each other. The most easily oxidisable bodies are always electro-positive to the less easily oxidisable. Oxygen itself may therefore be taken as the most electro-negative body, and potassium the most electro-positive; while all other substances occupy intermediate positions.

215. *Voltaic Battery.*—The current from a single pair of dissimilar plates in a voltaic cell is necessarily only weak, and when very powerful currents are required, it is usual to employ a number of these cells coupled together, which is termed a *voltaic battery.* It is also found that platinum or carbon forms a much better – element than copper, because more electro-negative, and two liquids within the cell a much more powerful arrangement than only one. When two liquids are used, it is, however, necessary to keep them apart by a porous partition. One of the most powerful and efficient arrangements in use is called the Bunsen Cell (Fig. 73), from the name of the inventor, Professor Bunsen. It consists of an earthenware or glass jar, V, within which is placed a plate of zinc, Z, bent into a circular form, and amalgamated with mercury, so as to prevent local chemical action. Within the interior of this zinc plate a porous earthenware jar, P, is inserted, and within this porous jar a solid block of dense carbon, C, is placed. The space between the outer jar, V, and the porous jar is filled up with a dilute solution of sulphuric acid and water—about one-tenth acid—and the space round the carbon element within the porous

cell with strong nitric acid. When the wire from the zinc plate and the wire from the carbon plate are brought together, a current passes between them. The connection with the carbon, which forms the + pole, is made by inserting a metal plug into the opening at the top, or by uniting it to the carbon by means of a binding screw. The complete cell is shown at the end of the figure. Any number of these cells may be joined together so as to form a more powerful arrangement. When they are joined with all the zinc plates together, and all the carbon plates together, we say they are arranged for *quantity*,

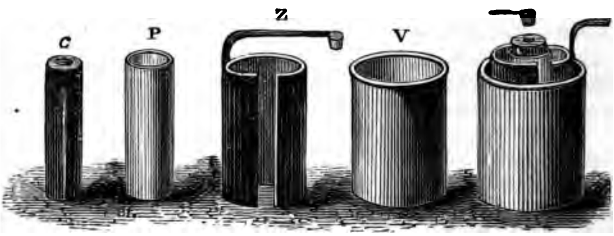


Fig. 73.—Bunsen Cell.

and give the same result as one large cell with an equal area of zinc and carbon. When they are arranged with the zinc and carbon coupled alternately, we say they are arranged for *intensity*, and the electro-motive force of one cell is added to the others, in proportion to the number, so that the current becomes much more energetic. When the two ends of the wire from the two poles of a voltaic battery are united, the current flows along the wire, and its strength and intensity are proportional to the size of the cells and the number in circuit. If the wires are disunited, the electricity ceases to be *dynamic*, but the two poles become charged with *static* electricity in opposite conditions. The strength of this statical charge is proportional to the strength of the dynamical electricity. The strength of a current corresponds to

the quantity or mass of water which is flowing down a river or through a pipe, and the intensity of a current to the velocity with which the water is moving. There are many other forms of voltaic batteries, but for these the student must be referred to special works on electricity.

216. *Laws regulating Electric Currents.*—The metallic plates and liquids within the battery offer a resistance to the passage of the current, and outside the battery the conducting wires also offer resistance. In consequence of this, the electric tension in the wire is less as the length becomes greater. The force which urges the current forward, and which arises from the chemical action within the battery, is called the *electro-motive force,* and this is the equivalent of the electric potential in any part of the circuit. This is much less in voltaic than frictional electricity, and hence the latter can overcome much greater resistances than the former. The decrease in the electric tension arising from the resistance of the wire is called the *electric fall.* The relations existing between currents and the resistance in the circuit were fully investigated by Professor Ohm, and the following is therefore called *Ohm's Law.*

217. *Ohm's Law.*—The strength of any electric current varies directly as the electro-motive force, and inversely as the total resistance of the circuit. From this it follows: (1) The resistance of any uniformly conducting wire is directly proportional to its length; (2) the resistance is also inversely as the area of its cross section, so that thick wires of the same material are better conductors than thin wires; (3) the resistance also depends upon the nature of the conducting medium, and differs for every substance. This difference in resistance is called the *specific resistance* of the material.

218. *Effects of Voltaic Currents.*—The effects produced by voltaic currents may be considered as (1) chemical, (2) heating and luminous, (3) magnetic, (4) physiological.

219. (1) *Chemical Effects.*—When the two ends of

the wires from any voltaic cell, and which are termed *electrodes*, or poles, are immersed in an electrolyte, the effects produced are exactly the reverse of those which occur within the cell itself. The electrolyte is decomposed, but the hydrogen or its analogue appears at the negative wire, which comes from the positive element in the battery; while the oxygen or its analogue appears at the positive wire, which comes from the negative element in the battery. Whenever two substances enter into chemical union, their combining proportions are always a definite quantity; and whenever decomposition is produced by the electrolytic action of a voltaic current, the elements are always liberated in the same definite proportions. The decomposed elements always appear at the surface of the electrodes, and never in the space between them. Upon this law depends the process of *electro-plating*, by means of which a metallic deposit can be fixed upon any conducting substance attached to the − pole in an electrolyte, of which one of the components is a metal, such as silver, gold, copper, &c. The amount of decomposition in the electrolyte is directly proportional to the chemical action which occurs within the battery. In consequence of this, the quantity of electricity passing through any circuit can be measured by the amount of electrolytic action which it can produce. An instrument which measures this action by the amount of water decomposed is called a *Voltameter*.

220. (2) *Heating and Luminous Effects*.—If a thin conductor of high resistance to the passage of the electric current be inserted between the poles of a voltaic battery, it will become heated; and if the resistance be great enough, and the current strong enough, it will become incandescent. Upon this depends the production of the electric light, in such lamps as Edison's or Swan's, where a thin ribbon of carbon is raised to a white heat. If the poles be metal, or the resisting wire metal, such as platinum, the heat in a powerful current will melt it. When carbon poles are used, and a space left between

them, with strong currents a brilliant arc of light passes, while a portion of the carbon is carried in the current from the + to the − pole, and the whole intervening space becomes luminous, both carbon poles being raised to a white heat. Upon this principle depends the production of the *arc* light, as in the case of the Siemens, Brush, and other lights. The total heat and light which can be generated in any circuit is always directly proportional to the amount of chemical action in the exciting battery, and bears a definite relation to that chemical action. In this way the strength of the current may be measured by the relative length of a given size of platinum wire which it will heat, as compared with any other current.

221. (3) *Magnetic Effects.*—If a wire along which an electric current is passing is placed horizontally over the surface of a compass needle, in the direction of its length, the needle will immediately change its position, and move round until it sets itself at right angles to the wire conveying the current. The current of electricity evidently, therefore, acts like a magnet on the needle, and repels both poles to the farthest distance from it. When the current ceases to flow, the needle returns to its original position in the same direction as the wire. This magnetic effect enables very feeble currents to be detected, because if the needle be suspended in such a manner that the wire can be carried in a coil above and below the needle, so that the current shall circulate round it, the magnetic effects will be increased in proportion to the number of convolutions. Upon this principle a very delicate instrument, called a *Galvanometer*, is constructed, which measures the strength and intensity of electric currents. Fig. 74 is an illustration of a simple form of this instrument. Two needles are poised on a central axis, and arranged so that the north pole of the one corresponds to the south pole of the other, and thus they almost neutralise each other's magnetism, and are thus rendered more sensitive to disturbing action. In this condition

the needles are said to be *astatic*. The axis passes through the centre of a coil of wire, round which an electric current can be sent. When no current is passing, the coil is set with its longer axis in the direction of the length of the needles—that is, from north to south. When a current passes, the needles immediately set themselves at right angles to the coil, as in the figure. If the current is too feeble to cause the needle to move through the whole range, the angular deviation is read off on to the scale to which one of them points. The coil is preserved under a glass shade, to prevent currents of air from disturbing the needles. In the most delicate instruments the needles are suspended by an unspun silk thread. When strong currents have to be measured, the galvanometer is unsuitable, and another instrument is employed, called a *tangent compass*, or tangent galvanometer, where the current passes round a thick brass ring placed in the magnetic meridian, with a small compass in the centre, at right angles to the plane of the ring. When the current passes round the ring, the tangent of the angle of deflection of the needle is proportional to the strength of the current. The direction in which the current flows determines the direction of motion of the needles; and in consequence of this, with suitable arrangements, called *commutators*, for reversing the direction of the current, the balanced needles can be made to move right or left at pleasure. On this principle all the *needle instruments* used in the electric telegraph are constructed.

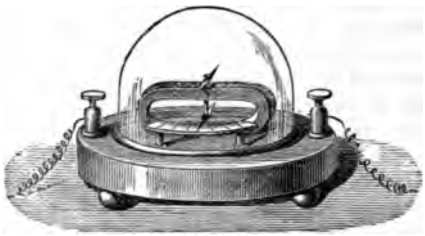


Fig. 74.—Galvanometer.

222. (4) *Physiological Effects.*—We have already seen that when the current from a Leyden jar or battery is passed through the human body a smart shock is experienced. The effects of voltaic currents are not so great, because the intensity is much less, but they can cause muscular contraction and powerfully affect the nervous system, and on account of this electric currents are now frequently used for medical purposes.

III. ELECTRO-MAGNETISM.

223. *Magnets.*—The ancients were acquainted with natural magnets, or loadstones, which possessed the power of attracting iron and steel, and when a piece of iron is rubbed with one of these loadstones it acquires similar properties. When a bar of steel has this property communicated to it, it is called a *magnet.* When suspended by a thread, the magnet always arranges itself in a direction pointing with its length nearly north and south. This direction is called the *magnetic meridian*, and in the same magnet the same end always assumes the same direction, and hence we term one end of the magnet the *north*, and the other the *south pole.* The *mariner's compass* is a familiar instance illustrating this property which the magnet possesses. In magnets it is usual to mark the north end, so that it can be recognised without suspending it, and hence it is sometimes called the *marked* pole. When another magnet is presented to a suspended magnet, the north pole of the one repels the north pole of the other, while the south pole attracts it, and *vice versa.* Like poles, therefore, always repel each other, while opposite poles attract. However small a magnet may be, it always possesses these two poles, and if a magnet is cut into two halves, each half immediately becomes double-poled, and acts in every respect as the magnet before it was divided. If the magnet is placed in a jar of iron filings, they are immediately attracted to the magnet, and attach themselves to it, but the largest quantities are at the two extremities, and the

number falls off from the ends to the centre position, where all attraction ceases. The attraction of the two ends is always equal. When the iron filings are attached to the magnet, they acquire magnetic properties, and attract their fellows, but lose this property when their attachment to the magnet ceases. Some substances, such as steel, retain their magnetism when separated from a magnet, and hence a natural steel bar may be changed into a magnet by contact with a magnet, or, better still, by passing the opposite poles of two magnets along the bar from the centre, so that the north pole of one magnet is drawn towards the south pole of the other. The magnet is then said to be produced by *induction*. Permanent magnets are frequently made in the form of a U, with the north and south poles bent up towards each other, and a soft iron piece placed across from pole to pole, so as to connect them together, which causes the two opposite magnetic attractions to intensify each other, and thus preserves the magnetism of the bar. Such a magnet is termed a *horse-shoe magnet*, and the soft iron connection the *keeper*.

Magnetic influence is not only exercised upon neighbouring bodies by a magnet when in contact with them, but also through a considerable space around it, so that a bar of soft iron becomes magnetic even when an interval of space separates it from the inducing magnet. The force or strength with which any magnet attracts or repels another is called the *magnetic force*, and this force varies inversely as the square of the distance from the magnetic pole. The space between the two poles of a magnet within which this attraction exists is called the *magnetic field*.

224. *Magnetic* and *Diamagnetic Bodies*.—Substances which, like soft iron, are attracted by magnets are called *magnetic*, and they are attracted whichever pole they are presented to; but there are also a large number of bodies, amongst which are some metals, such as bismuth and antimony, which are repelled by either pole. These

bodies are spoken of as *diamagnetic.* When magnetic bodies are placed within the magnetic field of two powerful magnets, they arrange themselves with their greatest length from pole to pole, while diamagnetic bodies arrange themselves with the greatest length at right

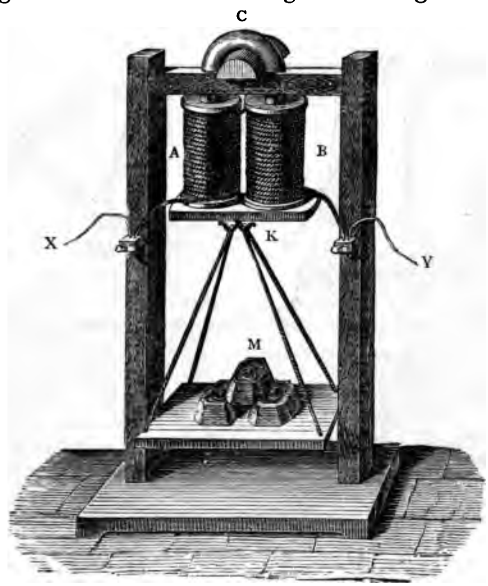


Fig 75.—Electro-magnet.

angles to the line joining the poles. All bodies have been found to be more or less magnetic or diamagnetic.

225. *Electro-magnets.*—We have already seen that an electric current affects a magnetic needle, and that this effect is proportional to the number of times which the current circulates round the needle. If, however, an electric current is passed, not round a magnetic needle, but round a soft iron bar, the bar becomes a magnet,

and retains its magnetism so long as the current passes, but loses it whenever the current ceases. In this way very powerful magnets can be formed. Fig. 75 is an illustration of such a magnet. A soft iron bar, C, is bent into the U shape, and the two ends surrounded by coils of wire wrapped on to two bobbins, A and B. When a

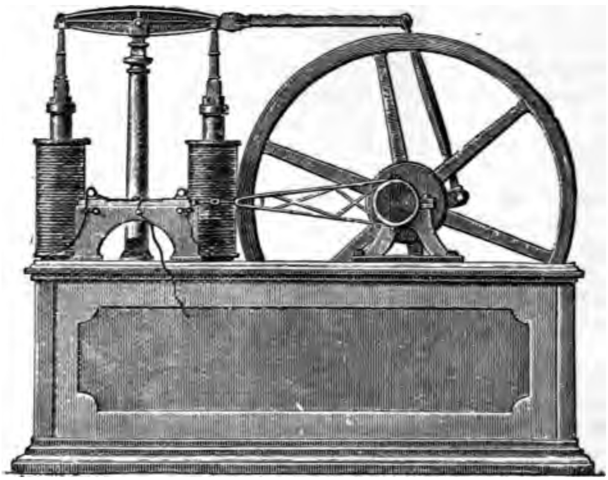


Fig 76.—Electro-Magnetic Engine.

current of electricity is passed round the coils, through the wires from X to Y, the soft iron core becomes a magnet, and attracts the keeper, K, with a force sufficient to sustain the heavy weights placed on the board, M. When the circuit is broken and the current ceases to flow, the soft iron immediately loses its magnetism, and the weights fall to the ground. By this means far more powerful magnets can be made than by any other process, and when a steel core is substituted for the soft iron, the steel becomes a permanent magnet. The fact

that soft iron loses its magnetism whenever the current ceases to flow is taken advantage of in the construction of electro-magnetic engines, by means of which the energy of a current of electricity can be changed into mechanical motion. Fig. 76 represents one form of these engines. Two keepers are arranged at the two ends of a reciprocating beam, immediately above two double coils with soft iron cores. The current of electricity is alternately passed through them by the action of a sliding bar, worked from the crank shaft by means of an excentric. When the current is passing through one of the sets of coils, the core becomes a magnet, and attracts the keeper, and thus draws down the one end of the beam. The current is then broken, and the attraction ceases on that keeper, and the current being transferred to the other coil, the keeper at the other end of the beam is attracted and drawn down, lifting up the other keeper again, so as to be ready for the next attraction. In this way the reciprocating motion is obtained, and transferred by a long lever attached to one end of the beam to the crank arm, and so to the crank shaft and fly-wheel. The momentum of this wheel carries the machine over the dead centres, just as in a steam-engine. Many of the machines used for telegraphic purposes, such as the call bells, and the means by which the carbon poles in the arc electric lights are made to approach each other automatically as the carbon is consumed, are constructed on this principle of momentary magnetism, induced in a soft iron core by the passage of an electric current.

226. *Induction Currents.*—While an electric current can be made to produce a magnet, the converse is also true, and a magnet can also be made to produce a current of electricity. An electric current can, indeed, be produced in any closed circuit, either by moving a magnet near to it, or by moving the circuit across the magnetic field. Further than this, it is found that any electric current whose strength is changing can produce another current in any closed circuit which is near to it.

Currents of electricity produced by any of these means are called *Induction currents.* The current which causes the induction is called the *primary* current, while the induced current is called the *secondary* current.

227. *Currents produced by Magnets.*—If we take a coil of insulated wire, and connect it with a delicate galvanometer, and insert a magnet within the coil, a momentary current is induced in the coil, which will deflect the galvanometer needle. When the magnet is withdrawn from the coil, a similar induction current is produced, only in an opposite direction along the wire. In the same way, if the magnet is allowed to remain at rest, and the coil is moved over the magnet and withdrawn from it, similar currents are produced. The strength of these currents depends upon the strength of the exciting magnet, and the rapidity with which the magnet or coil is moved. It is upon this principle that the powerful currents required for the production of the electric light are generated. Coils of wire, arranged in various ways, are made to rotate by steam, gas, or water-power between the poles of sets of very powerful magnets, and the currents generated in them can be changed into one direction by means of suitable commutators, and collected together into one powerful current, which far exceeds any current in strength which can be economically produced by chemical means. As a rule, the magnets in these *Dynamo-electric machines* are themselves produced by the passage of the electric current round soft iron cores. Advantage is usually taken of the fact that even soft iron, when once magnetised, does not entirely lose its polarity when the current ceases. A certain *residual magnetism* therefore remains in the soft iron when the machine is at rest. When the machine is set in motion, feeble currents are generated in the coils, and these, passing round the soft iron cores, exalt the magnetism, and thus increase the strength of the magnets. This again re-acts upon the currents, which increase in strength, therefore, proportional to the speed with which

the machine revolves. These machines are the exact reverse of electro-magnetic engines, in which a current of electricity is changed into mechanical motion (225); but any of the continuous current dynamo machines can be used as electro-motors, because when a current from an independent source is introduced into them the armature revolves with great velocity. Power can thus be transmitted to a distance.

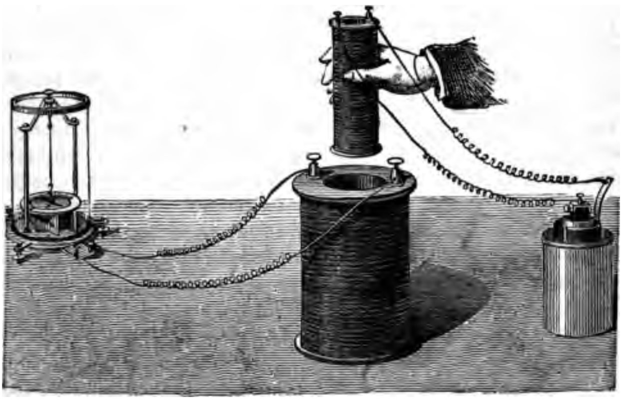


Fig. 77.—Induction Currents.

228. *Currents produced by Currents.*—If a long coil of wire wound into a hollow bobbin is connected with a delicate galvanometer, a current of electricity is produced in it when a similar smaller bobbin with a current circulating round it is introduced into the centre of the larger bobbin. This arrangement is shown in Fig. 77. The strength of the induced current is much increased by placing a core of soft iron within the primary coil, which is the little bobbin. If the small bobbin and soft iron core is allowed to remain within the large bobbin, the induced currents cease, even although the current from the battery is passing; but if the current from the

battery is made discontinuous, by rapidly breaking the circuit, the same effect is produced as if the inner bobbin was lifted out and in with equal rapidity. This breaking of the circuit can be accomplished by various mechanical means, and when this is done rapidly, momentary currents in opposite directions are produced in the secondary coil of very great intensity, far exceeding that of the primary circuit. The tension or intensity of the induced current is proportional to the strength of the primary current, and to the square of the resistance in the secondary coil. Hence, the finer the wire, and the greater the length in the secondary coil, the more intense are the currents induced in it. They are also inversely proportional to the duration of the primary current, so that the more rapid the circuit is broken the more intense are the induced currents. The strength and intensity of the secondary currents are greatly increased by the introduction of a *condenser* into the primary circuit. This condenser is formed of a series of plates of tin-foil, insulated from each other, the alternate plates of which are connected with opposite poles of the primary circuit. This acts like a Leyden battery, and shortens the duration of the primary current when the circuit is broken by the contact-breaker. It is upon this principle that Ruhmkorff constructed the *induction* or *intensity coil.* The currents produced by large intensity coils are like small flashes of lightning, and far exceed in quantity those produced by friction or other means. They will instantly charge large Leyden jars, and produce the most beautiful luminous effects when passed through sealed tubes from which the air has been partially exhausted. Nothing can exceed the beauty of the effects produced within these tubes when they are arranged in different forms, and filled with various attenuated gases, and especially when they are caused to rotate at right angles to the direction of their length. One of the most curious results is the formation within the tube of dark curved bands, or stratifications, at right

angles to the direction of the current, and which move forward from the + to the − pole.

229. *Relation of Electricity to Magnetism.*—The production of electric currents by the motion of magnets, and of magnets by the circulation of electric currents round non-magnetic bodies, indicates that there must be a close relation between the two phenomena. Ampère suggested that magnets are nothing more than bodies in which all the molecules are arranged with their like poles in one direction, and that round every individual molecule of a magnet electric currents are ceaselessly circulating. Professor Clerk Maxwell came to the conclusion that the longitudinally set molecules which form a magnet are all rotating on their longer axis, and suggested that if a similar motion is taking place in the ether, which forms the medium of light, it will produce tensions along the lines, and pressures at right angles to them, and afford a satisfactory explanation of the magnetic attractions and repulsions which occur across empty space, and appear to be the cause of magnetic induction at a distance.

230. *Terrestrial Magnetism.*—Owing to the unequal heating of the surface of the earth, and its rotation in space, as well as probably from other causes, the earth acts as if it were a magnet, and it is in consequence of this that a needle when freely suspended points north and south. The poles of rotation of the earth do not, however, exactly coincide with the magnetic poles, and hence the needle does not point exactly to the north and south poles. The magnetic north pole is about 1,000 miles from the geographical pole, the direction in the British Isles being to the west. This deviation from the true north is called the *magnetic declination.* If the needle is suspended in a vertical instead of a horizontal direction, it is found that it does not lie in a horizontal plane, but dips at one end. This *dip* or *inclination* of the needle is about 67° 39′ at the present time in England, and at the magnetic pole it would be 90°, so that the needle would

be vertical. Both the declination and dip are subject to continual variation every day, and to slower changes, which depend upon the position of the earth in its orbit and other causes, some of which extend over many years. Sudden variations are termed *magnetic storms*, because they indicate great variations in the intensity of the earth's magnetism, and are often accompanied by electrical disturbances in the atmosphere, which are exhibited in such phenomena as the *Aurora borealis*, &c. These changes also appear to be in some way connected with the appearance and number of spots on the surface of the sun.

IV. THERMO-ELECTRICITY.

231. *Electric Currents produced by Heat.*—We have already seen (220) that when a current of electricity passes through a conductor which offers great resistance the conductor is heated. When the wire is sufficiently small in diameter, or the current very strong, the wire will be raised to incandescence, or even melted. When any closed circuit is formed of two dissimilar metals, and the point of junction of the two is heated, a current will pass from one to the other round the circuit. Two dissimilar metals are not, indeed, necessary, for if the same metal, except in the case of lead, be unequally heated on two sides of the point of junction, a current will pass in the direction from the hot to the cold end. When the same metals are used, the thermo-electro-motive force is proportional to the difference in temperature between the two parts. When a number of these unequally heated metal junctions are joined together in circuit, a *thermo-electric battery* is formed, and the total electromotive force is proportional to the sum of the thermo-electric forces at the several junctions.

232. *Thermo-piles.*—When it is desired to obtain thermic couples which will exhibit the greatest amount of sensitiveness to heat, such as radiant heat, it is usual to make the thermo-electric couples of two metals which

exhibit the most thermo-electro-positive and electro-negative properties. Bismuth and antimony stand at opposite ends of the scale in this respect; and hence, when a number of couples of these two metals are arranged in circuit, so that all points of junction can be subjected to the action of the heat rays, we possess a means of determining minute differences of temperature which far exceeds the ordinary thermometer. Such an arrangement of couples is called a *thermo-pile*, and is used along with a short coil galvanometer with astatic needles. The strength of the electric current generated by the pile is measured as in the ordinary galvanometer, and is thus a measure of the heat falling upon the face of the pile.

V. ANIMAL ELECTRICITY.

233. *Animal Electricity.* — We have already seen (222) that when an electric discharge or electric current is permitted to pass through the animal organism, violent muscular contractions are the result. There are, however, other electrical phenomena which are manifested. All furred animals, such as the cat, when in a dry condition, and the fur excited by friction, are capable of giving off sparks, and the same applies to the human body, which, when dry and insulated, becomes charged by the friction of the clothes with the skin, and under suitable conditions will give a spark. All muscular movements are also accompanied by the passage of electric currents along the nerves.

234. *Electric Fish.*—The most remarkable instance of animal electricity, however, occurs in the case of the two singular fishes, the *Raia torpedo*, a species of ray, and the *Gymnotus electricus*, a species of eel. The former is provided with an electric organ, situated on the back of its head, by which it can give a most powerful shock, probably as a means of defence; and the latter, although not so powerful, can, when excited, also give a very strong shock.

VI. APPLICATIONS OF ELECTRICITY.

235. *The Telegraph.*—The applications of electricity become more numerous every year. At an early date the passage of electricity along insulated wires suggested the possibility of conveying messages instantly to any required distance. It has been found that only one wire is required, because the earth serves in all cases as a return wire, to complete the circuit. The currents of electricity may be generated from any source, and the recording instruments comprise either single needles, the oscillation of which can be made to represent the alphabet or code, or automatic machines, embodying clock-work, electro-magnetic engines, or other suitable machines for transmitting and self-registering the message, either in a code or by ordinary printing. All these methods are now employed, and wherever the wires are carried, whether buried in the earth, suspended in the air, or sunk in insulated cables beneath the surface of the sea, the messages also are carried and read, and thus the electric wires, like the nerves of the human body, connect together the far-scattered children of men.

236. *The Telephone.*—The telegraph, which records only graphic messages, has found a formidable rival in the telephone. We have already seen that if a magnet is moved in the presence of an insulated coil of wire in closed circuit, a current is generated in it, and the same effect occurs if the intensity of the magnetism of the magnet is undergoing a change. If, therefore, a coil of insulated wire is wound round the end of a permanent magnet, and a keeper of soft iron is made to approach and recede from the face of the magnet, then electric currents are generated in the surrounding coil. In the telephone the keeper is a thin plate of iron, which vibrates with the sound waves produced by the voice, and being in front of the permanent magnet, its magnetic state is altered, and a current produced, which *varies* exactly as the keeper is vibrating. At the other

end of the circuit a similar instrument is placed, but in this the process is reversed, for the currents traversing the coil re-act on the permanent magnet, and as its magnetism varies the thin keeper in front is thrown into responsive vibration, and thus reproduces in the air the original sounds. It is usual now to use a transmitting instrument, in which, by means of a *microphone*, the motion of the original sound waves is augmented by the vibration of a small loose piece of carbon. This motion is also in some forms further increased by the introduction of another current into the circuit, and thus the faintest sounds, such as the ticking of a watch or the footsteps of a fly, can be heard at the distance of miles. This instrument promises to be of great value in a medical point of view, because it enables variations of sound to be detected which escape the ordinary stethoscope.

237. *The Photophone.*—Several bodies, such as selenium, undergo a change in their power of conducting electric currents when exposed to the action of light, and on this principle an instrument has been constructed by means of which the vibrations of a plate, as in the telephone, are made to reflect a ray of light with varying intensity on to a suitable selenium receiver. The current which is passing through the receiver, therefore, varies in intensity, and acts upon a telephone which is placed in the same circuit, thus reproducing sounds as in the telephone.

238. *The Electric Light.*—We have already noticed (226) that the dynamo machines enable very powerful currents to be produced by the agency of mechanical power, and this has led to a very much larger use of electricity as an illuminating agent than when currents could only be obtained from chemical batteries. The production of intensely powerful arc lights is therefore now practical, and for the illumination of large spaces, and where great light is required, is daily coming more into use. The production of thin carbon filaments in a

vacuum, which can be raised to incandescence by the passage of a current of electricity, has also led to the possible division of the current into a number of lights of great softness, brilliancy, and steadiness. The use of large arc lights is interfered with by the unsteadiness of the light, arising from the fracture of the carbon poles under unequal expansion, and the difficulty of properly regulating the approach of the poles to each other as the carbon consumes. The great variation in the light which occurs when the motive power of the dynamo machine varies also is another cause of difficulty, and this is intensified by the fact that the motor must be kept constantly working during the whole time the light is required, for if it stops the light instantly ceases.

239. *Storage of Electricity.*—The last-named difficulty has led to the endeavour to find a means of accumulating a supply of electricity which can in some way be connected into the circuit so as to equalise the current under fluctuations in its production, as well as maintain the light when temporary stoppage of the generator occurs. It has long been known that whenever a current decomposes an electrolyte in a voltaic cell, a certain portion of the elements of which the electrolyte was composed are deposited on the two plates which form the poles, and when the original current ceases a new current is generated in an opposite direction by the action of these deposited films. By arranging a series of cells which contain terminal plates, specially prepared with coated surfaces, so that they will accumulate the elements of the electrolyte when a circuit is passed through them, very powerful *secondary batteries*, as they are termed, are produced; and when the original current is stopped, the reverse currents given out are both powerful and regular. Secondary batteries are, indeed, only voltaic batteries worked backwards, in which, by the action of the original current, a certain amount of chemical work is performed and stored up in a loose form of combination, so that when the original current ceases the chemical

action is reversed, and the original energy re-appears in the reverse current. Considerable difficulty still exists in obtaining properly prepared surfaces, and securing regularity and permanence in the secondary currents; but should success crown the many efforts which are now being made in this direction, it will enormously increase the efficiency of the electric light. In addition to this, it will enable the intermittent forces of nature, such as winds and tides, to be utilised in the production of electric currents, and hasten the use of electricity as a motive power.

Part V.

MOLECULAR PHYSICS, INCLUDING CHEMICAL PHYSICS AS A SPECIAL BRANCH.

CHAPTER I.

COMPOUNDS AND ELEMENTS.

240. *Kinds of Matter.*—We have already seen (29) that there are certain distinctive peculiarities which matter, as such, always displays, and upon which depends all our knowledge of its existence. These peculiarities we term the *essential properties* of matter, because they are its characteristics wherever we find it, and in whatever state or condition it exists. There is another class of properties, which we term *specific*, which are of two kinds, the first depending upon the state or condition of the matter at the time our observations are made, whether it is solid or liquid or gaseous ; and the second, upon the particular nature and properties of the matter itself, such as whether it is gold, or potassium, oxygen, sulphur, &c. So far, in considering the relations of matter to force, we have taken little account of the second class of these specific properties, although they have a very important bearing upon the relation of the various kinds of matter to each other.

Under the action of purely mechanical force, such as *gravitation*, all matter deports itself in a similar manner,

because the re-action depends upon the essential properties of matter. To a certain extent also the same remark applies to the first of the specific properties, because the action of gravitation is the same upon matter whether in the solid, liquid, or gaseous state. When, however, we come to consider the action of other forces, such as heat, or light, or electricity, which are intimately related to the nature of matter and the state in which the matter exists, and so to all its specific properties, the case is entirely different, and we are obliged to consider the distinctions which exist between one kind of matter and another. These distinctions, as we shall afterwards see, are quite independent of the state in which the matter may exist, and depend upon essential differences in its nature.

241. *Distinction of Matter.*—The essential differences in the nature of matter form a distinct branch of study, which is termed *chemistry*, and which seeks to determine how many different kinds of matter exist, and the properties which they possess, as well as the compounds which they form when combined together. Chemistry thus divides all the matter of which the earth is composed into two primary classes, called *compound* and *simple*. Compound bodies are those which can be decomposed or broken up into two or more different kinds of matter, each of which exhibits entirely different properties from the matter out of which it was obtained. Simple bodies are those which consist of one kind of matter only, and resist all efforts which the chemist employs to break them up into any other kinds of matter. Simple bodies have received the name of *elements*. If the world were formed of one element only there could be no science of chemistry, although all the strictly physico-mathematical sciences might exist, because the element would still be subject to the action of force, and might, therefore, assume a great variety of physical and molecular conditions, as well as act and be reacted upon by other masses of matter at a distance.

242. *Compound Bodies.*—The science of chemistry has demonstrated that the great mass of the crust of the earth, and the surrounding water, is formed of compound and not simple bodies, and that these compound bodies are characterised by certain properties, which are inherent in them, and always manifested in the same substance wherever it may be found. These various substances differ very much in the complexity of their composition, some being capable of resolution into only two, and some into many different kinds of simple substances. They also differ widely in the degree of fixity which they possess, and consequently of resistance which they offer to any attempt to decompose them. The chemist has to use many different agents to bring about the decomposition of compound bodies, and the use of these various agents is termed the process of *analysis.* When the analysis is made simply to determine the nature and number of the constituents of a compound it is termed *qualitative* analysis, but when the various constituent parts are weighed, so as to determine the gravimetrical relation of the constituents, it is termed *quantitative* analysis. Most compound substances become analysed into their constituents when subjected to heat, and, indeed, it is extremely probable that under a sufficiently high temperature all known compounds might be decomposed. In the intensely heated atmosphere of the sun, and some of the fixed stars, there is reason to believe that some of the substances, which chemists regard as elements, are really dissociated, and this may explain some of the anomalies exhibited by the lines visible in the solar and stellar spectra. Many substances which resist the action of very intense heat are readily decomposed when acted upon by other bodies, especially when in a liquid condition, or a state of solution. Others, again, which remain unchanged under the action of heat or chemical re-action, are instantly decomposed when subjected to the influence of an electric current. We have already seen this in the decomposing action of an

electric current upon an electrolyte (214). Light is also a powerful decomposing agent, of which we have familiar examples in photography, and in the living cells of plants under sunlight. Mechanical causes may also act in the same manner, as in the effects of great pressure, or impact causing percussion. A familiar case of the latter occurs when a percussion cap or detonator is fired.

Most of the operations which are occurring in the world around us, and especially in the growth and decay of living organisms, arise from the continual breaking up of compound bodies. These serve as food for the plants and animals, and the vital action determines their re-composition into other bodies of more or less complexity, which are either built up into the structure of the organisms, or returned into the outer world to undergo another series of changes in the great circle of nature. A similar series of changes, occasioned by the re-action of different kinds of matter upon each other, is also occurring in the inorganic world. All portions of the earth's crust, where exposed to the action of air and water, and deep down below the surface of the ground, wherever water and air, or water charged with various substances in solution, can penetrate, are the seat of continual chemical changes. These changes are accompanied and intensified by alterations in temperature and pressure, which are continually occurring, and which have resulted in the formation of all the minerals and metallic veins which constitute the various strata of rock and other formations. These re-actions are also one of the probable causes of earthquakes and volcanic phenomena.

Although all the various compound bodies which form the crust of the earth, and the organic structures which exist upon it, are formed out of a comparatively small number of elements, they each possess properties which are so distinctive that they can always be distinguished from each other, and these properties are also, in most cases, quite different from those which are charac-

teristic of the elements out of which they are formed. Thus common salt, which is a white crystalline body, and possesses very characteristic properties, which are well known, is a compound formed by the union of a soft silvery metal called sodium, with a pungent yellow gas named chlorine. By no mechanical means at our command can we subdivide salt into parts so small that they will not exhibit the properties of salt, and the union which subsists between two elements of which the salt is composed must, therefore, differ entirely in character from the mechanical state of aggregation of the minute parts of the compound body which build up its larger masses.

243. *Elements.*—The nature of the parts of which matter is composed has afforded food for speculation from the earliest times, because, although it was known to be built up of parts, it was thought that there might be no limit to the number, or in other words, if we had the power we might subdivide matter infinitely. If matter was, however, infinitely divisible, there would still remain the question how far we could divide the parts of which any specific matter is composed, and yet the subdivided parts retain the special properties which characterise that special matter in its larger masses.

We know that different substances possess very different properties, quite independent of the physical state in which they may be, and we have already seen (242) that, even in the case of compound bodies, no mechanical division will break them up into parts so small that they cease to exhibit the same properties which characterised the mass. Thus water and mercury are both liquids, and both may be made to assume the solid and gaseous state, but they are entirely different in their nature and properties, and this difference must arise either from an entirely different matter, or from some very different arrangement of the parts of the same matter. Chemistry, however, enables us to effect sub-

divisions which are quite impossible with mechanical means.

We have already seen (219) that when an electric current is passed through acidulated water a chemical change occurs, and the water is broken up into two gases, oxygen and hydrogen, so that there is evidently a limit to the subdivision of water, because we at length reach a point where any further subdivision produces not water, but two substances which are perfectly distinct from it. Mercury cannot, however, be divided into any other kind of matter, either by chemical or mechanical means. Further, this division of water into two gases reveals also the fact that the water is always composed of definite quantities of these gases, in the proportion of one part by weight of hydrogen to eight parts of oxygen: while the hydrogen, although so much lighter, always at the same pressure and temperature, occupies twice the volume or space occupied by the oxygen. The same volume of oxygen, therefore, always weighs sixteen times as heavy as the hydrogen. If we endeavour further to subdivide the hydrogen or oxygen by any means at our command, either mechanically or chemically, we find it impossible to do so, and these substances are therefore termed *elements*, because in the present state of our knowledge we suppose them to be matter in its simplest form. Chemists have examined and tested all known forms of matter, and about sixty-four substances have resisted all further decomposition up to the present time.

The following table gives the names of these elementary bodies, arranged alphabetically; also the symbol or abbreviation by which they are distinguished, and their relative weight when in the state of a gas, compared with the same volume of hydrogen which is taken as unity. This volume-weight relation to hydrogen is called the *atomic weight*.

TABLE OF ELEMENTS WITH THEIR SYMBOLS AND ATOMIC WEIGHTS.

Name.	Symbol.	Atomic Weight.	Name.	Symbol.	Atomic Weight.
ALUMINIUM ...	Al.	27·5	Molybdenum ...	Mo.	96·0
Antimony (Stibium)	Sb.	122·0	Nickel	Ni.	59·0
Arsenic	As.	75·0	Niobium... ...	Nb.	94·0
BARIUM	Ba.	137·0	NITROGEN ...	N.	14·0
Beryllium ...	Be.	9·3	Osmium... ...	Os.	199·0
Bismuth	Bi.	210·0	OXYGEN... ...	O.	16·0
Boron	B.	11·0	Palladium ...	Pd.	106·0
Bromine	Br.	80·0	PHOSPHORUS ...	P.	31·0
Cadmium... ...	Cd.	112·0	Platinum ...	Pt.	197·0
Cæsium	Cs.	133·0	Potassium (Kalium)	K.	39·0
CALCIUM	Ca.	40·0	Rhodium ...	Rh.	104·0
CARBON	C.	12·0	Rubidium ...	Rb.	85·0
Cerium	Ce.	92·0	Ruthenium ...	Ru.	104·0
CHLORINE ...	Cl.	35·5	Selenium ...	Se.	79·5
Chromium ...	Cr.	52·5	SILICON	Si.	28·0
Cobalt	Co.	59·0	SILVER (Argentum)	Ag.	108·0
COPPER (Cuprum)	Cu.	63·5	SODIUM (Natron)	Na.	23·0
Didymium ..	D.	96·0	Strontium ...	Sr.	87·5
Erbium	E.	112·0	SULPHUR ...	S.	32·0
Fluorine	F.	19·0	Tantalum ...	Ta.	182·0
Gallium	Ga.	69·8	Tellurium ...	Te.	129·0
GOLD (Aurum) ...	Au.	197·0	Thallium ...	Tl.	204·0
HYDROGEN ...	H.	1·0	Thorium... ...	Th.	115·7
Indium	In.	113·4	Tin (Stannum)...	Sn.	118·0
Iodine	I.	127·0	Titanium ...	Ti.	50·0
Iridium	Ir.	197·0	Tungsten (Wolframium) ...	W.	184·0
IRON (Ferrum) ...	Fe.	56·0	Uranium	U.	120·0
Lanthanum ...	La.	92·0	Vanadium ...	V.	51·0
LEAD (Plumbum)...	Pb.	207·0	Yttrium... ...	Y.	62·0
Lithium	Li.	7·0	ZINC	Zn.	65·0
MAGNESIUM ...	Mg.	24·0	Zirconium ...	Zr.	89·0
MANGANESE ...	Mn.	55·0			
Mercury (Hydrargyrum) ...	Hg.	200·0			

The elements which are most abundant and important in the economy of nature are marked by larger type.

These elements and their compounds are by no means equally distributed in the composition of the universe. Some of them, like thallium, are of exceedingly rare occurrence, while others, like oxygen and silicon, form about one-third of the solid crust of the earth, and oxygen and hydrogen the whole of the water. Few of the elements except oxygen and nitrogen in the air, and a few metallic bodies in the earth, exist in the pure state—at least so far as we know—because our knowledge of the earth's crust at any depth is very uncertain. We cannot, indeed, assert that there may not be many substances, both compound and simple, which we do not know as yet, and the belief strengthens that, as our knowledge increases, we may yet add considerably to their number.

It is possible that many of these bodies may really be compounds, but they are placed in this table because we have no means at present by which we can further subdivide them so that they will exhibit different properties from those which we know to characterise them. We suppose, therefore, that any quantity of any one of these substances, when in the pure state, always consists of aggregations of the same kind of matter, and that however small the quantity taken may be, it will always exhibit the same properties and no others. The science of Chemistry investigates the properties which each of these elementary bodies exhibits with regard to the others, the combinations which they are capable of entering into, and the re-actions which occur between them. Amongst the many facts connected with these combinations and re-actions, one stands out very prominently, viz., we cannot by any means at our command destroy the specific properties of any of these elementary bodies; we may mask them for a time by permitting them to enter into combination with each other, in which case new properties are exhibited; but when we decompose the compounds, the old properties of the elements always re-appear again without any

diminution or addition. Also we cannot, by any process, diminish or destroy the weight of matter which we use in our experiments, or produce by any combination a greater weight of matter in the compound than was present in the sum of the elements out of which we form it. The parts, therefore, of which the elementary bodies are composed are indestructible. We can divide any of these elementary substances into parts which are inconceivably small. A single grain of the nitrate of lead can be dissolved in 500,000 grains of water, and when a stream of sulphuretted hydrogen gas is passed through the solution the lead will appear as a solid, united with sulphur, in such a fine state of division that it will tinge every portion of the solution. One single drop of this solution, when spread over a square inch, can be seen by the microscope to contain portions of the sulphuret of lead in every part; and as the part so made visible is not greater than the $\frac{1}{1,000,000}$th of the square inch, it represents the $\frac{1}{500,000,000,000}$th part of the original water in which the one grain of nitrate of lead was dissolved. The amount of lead in the nitrate of lead was only $\frac{62}{100}$th of a grain, and therefore the portion of lead rendered visible under the microscope cannot exceed $\frac{1}{888,492,000,000,000}$th of a cubic inch, or weigh more than $\frac{1}{510,000,000,000}$th of a grain. Notwithstanding the smallness of the division, the lead still retains the peculiar properties by which it is distinguished. The elements, like the compound bodies, are therefore capable of very great subdivision; and since we do not, in the present state of our knowledge, think that they are formed of anything but the same kind of matter, the question naturally arises—can these elementary bodies be infinitely subdivided, even although the smallest part would always only contain the same kind of matter? Before this question can be answered it is necessary for us to know something of the nature of the relations which subsist between the elements themselves, and also the conditions under which they enter into combination

with each other. We shall then see that the consideration of the phenomena thus exhibited throws some light upon the subject, and enables us to arrive at a conclusion which is not founded upon mere guesswork.

244. *Properties of the Elements.*—The elements differ from each other very widely in the nature of the properties which they display, quite independent of the physical conditions in which they may be. Those which possess a high lustre, great opacity, and are good conductors of heat and electricity, are termed *metals*, while those which are destitute of these properties are termed *non-metals*. There is, however, no absolute distinction between them, since the two shade into each other so gradually that in the case of more than one of the elements it is difficult to determine to which of the two classes it belongs. Some bodies—such as gold, silver, iron, copper, etc.—possess the metallic properties in the highest degree, while others—such as arsenic and tellurium—are destitute of some of these properties, and are now usually considered amongst the non-metallic bodies. The metals are by far the most numerous, and comprise all the sixty-four elements, except fifteen, which may therefore be considered as the non-metals—viz., arsenic, boron, bromine, carbon, chlorine, fluorine, hydrogen, iodine, nitrogen, oxygen, phosphorus, selenium, silicon, sulphur, tellurium.

CHAPTER II.

LAWS OF COMBINING PROPORTION.

245. *Chemical Combination.*—Two different substances may be intimately mixed together so that their different parts cannot be afterwards separated, and yet remain only in a state of *mechanical mixture.* Thus, two gases,

oxygen and hydrogen, may be mixed in a strong glass vessel, and the two will occupy exactly the same space as the sum of the volumes of the two gases before the mixture was made, and they will remain in this state for any length of time. If, however, an electric spark is passed through the mixture an explosion occurs, accompanied by the disengagement of great heat, and a volume of steam is formed, which can be condensed into water. The two gases, which were formerly in a state of mechanical mixture, being each interdiffused with the other, have now entered into chemical union, or *chemical combination*, and a body differing entirely in its properties from either of the original gases has now been formed. The formation of a compound from its elements is called *synthesis*. A mechanical mixture and a chemical combination are therefore entirely different. In a mechanical mixture the proportions of the various component parts may be altered to any extent, and the resulting mixture will always exhibit properties which are the average of the properties of the various component parts, in proportion to their various quantities. In a chemical compound this is not the case, for the various substances of which it is composed will only enter into combination with each other in certain fixed and definite proportions which are constant in the same substance, and the properties of the compound are usually totally different from those of the elements out of which it is made, as well as from those of the mixture of the elements before they entered into combination. As a rule, also, while mechanical mixtures retain the same temperature as the average, and the sum of the volumes of the component parts, chemical combinations are accompanied by great changes both in temperature and volume. Many solids when entering into chemical combination become gases, and liquids become solids, while gases become liquids or solids, and the change is also accompanied by luminous and electrical phenomena.

246. *Constancy of Composition of Compounds.*—Whatever be the nature of the physical changes which accompany chemical combination, a given compound has always the same composition wherever it may be found, or under whatever conditions it may have been formed. Thus water may be obtained from condensed steam or melted ice—it may be taken from the well of an oasis in the desert, a spring on the mountain side, or the collected dew-drops from the blades of grass; but however formed or wherever obtained, it always consists of oxygen and hydrogen, and of 16 parts by weight of the former to 2 of the latter. Again, common salt, whether it is obtained from the mines of Siberia or the brine-wells of Cheshire, has always in it 35·5 parts by weight of chlorine to every 23 parts of the metal sodium. In the same way this law holds universally good with all other definite chemical compounds, they are invariably constant in composition. This law has no exceptions, and hence one absolutely accurate analysis of any substance for ever settles the nature of its ingredients.

247. *Law of Constant Proportion.*—One element may therefore unite with another element to form a compound; and in the same way, a compound may unite with another compound to form a still more complex compound than before. Even in this case, however, the compounds always unite together in certain definite proportions the same as the elements. This law of constant proportion, therefore, may be thus defined—*Numbers can be found for all bodies, whether they are simple or compound, which express the relative proportion by weight in which they will combine.* So far as the elements are concerned these combining weights are the so-called atomic weights already given in the table of elements (243).

Thus 35·5 parts by weight of chlorine will combine with one part by weight of hydrogen to form 36·5 ($35{\cdot}5 + 1 = 36{\cdot}5$) parts by weight of hydrochloric acid gas, and the numbers 35·5 and 1, or, as we shall afterwards

see (249), multiples of them stand respectively for the proportions of chlorine and hydrogen which enter into combination. Again, 14 parts by weight of nitrogen will unite with 3 parts by weight of hydrogen to form ($14+3=17$) 17 parts by weight of ammonia gas, so that 14 is the proportion in which nitrogen combines. Hydrochloric acid and ammonia are, therefore, two compound bodies, each formed by the combination of two elementary bodies, and they may themselves be caused to enter into combination, and they will do so in the proportions of 36·5 parts of hydrochloric acid and 17 parts of ammonia to make ($36{\cdot}5+17=53{\cdot}5$) 53·5 parts of chloride of ammonia. From this it will be seen that we have, therefore, another law unfolded—viz., the law of compound proportion.

248. *Law of Compound Proportion.*—This law may be defined as follows: *that the combining proportion of a compound is always the sum of the combining proportions of its component elements.* This compound weight, which is obtained by summing up the combining weights of the elements which form the compound, is called the *molecular weight.* Thus, just as 1 is called the atomic weight of hydrogen, or 14 the atomic weight of nitrogen, or 35·5 of chlorine, so 36·5 is called the molecular weight of hydrochloric acid, and 17 that of ammonia, or 53·5 the molecular weight of chloride of ammonia.

249. *Law of Multiple Proportion.*—We have already stated (247) that elements may enter into combination with each other in more proportions than one, and we have thus another law unfolded which is termed the law of multiple proportion, and may be defined as follows: *If two elements, or compounds, are capable of uniting in several proportions, the higher proportions of one of them are always multiples of its first or lowest proportion.* The compounds of nitrogen with oxygen form a striking example of the truth of this law, because oxygen can enter into combination with a molecule of nitrogen in *five different* proportions; and if we call the lowest com-

bining weight of oxygen, which is 16, unity, we have in the remaining compounds multiples by 2, 3, 4 and 5 of the weight of oxygen. This will be clearly seen from the following table—

	Parts by Weight.		*Parts by Weight.*	
Nitrogen monoxide	$(14 \times 2) = 28$	nitrogen to	$(16 \times 1) = 16$	oxygen.
Nitrogen dioxide	$(14 \times 2) = 28$	"	$(16 \times 2) = 32$	"
Nitrogen trioxide	$(14 \times 2) = 28$	"	$(16 \times 3) = 48$	"
Nitrogen tetroxide	$(14 \times 2) = 28$	"	$(16 \times 4) = 64$	"
Nitrogen pentoxide	$(14 \times 2) = 28$	"	$(16 \times 5) = 80$	"

The power to enter into combination in varying proportion with other elements is not equally shared by all the elements. This points to a difference in the nature of the elements which is of great importance, and which has been termed *atomicity*, of which more hereafter (255).

250. *Densities of Elementary and Compound Gases.*— Hydrogen is the lightest of all the elementary gases, and a litre of it, which is about 61·027 cubic inches, weighs about 1·379 grains, or ·08936 grammes in French measure, under standard conditions of temperature and pressure. Under the same conditions one litre of nitrogen gas weighs exactly 14 times this weight, while an equal volume of chlorine gas weighs 35·5 times. These numbers, however, 14 and 35·5 are the atomic weights of nitrogen and chlorine, and as the weight of the same volume of all the elements is always the weight of the litre of hydrogen multiplied by the atomic weight, it follows that, taking hydrogen as the standard for the specific gravity of the gases, *this specific gravity, or density of the elements in the gaseous state is identical with their atomic weights.* Phosphorus, arsenic, mercury, and cadmium are exceptions to this law for which the reader must be referred to works on chemistry. The densities of the elementary gases being identical with their atomic weights, it is apparent that when 35·5 parts by weight of chlorine combine with 1 part by weight

of hydrogen, we have equal volumes of chlorine and hydrogen combining together, and it is important to see, now, what is the density of the compound gas formed by them. It is found by experiment that 1 volume of chlorine and 1 volume of hydrogen when united together form two volumes of hydrochloric acid, and the volume of hydrochloric acid gas is therefore twice the volume of either of its component parts. In the case of ammonia which is formed of one volume of nitrogen to 3 volumes of hydrogen $(1 + 3 = 4)$, it is found by experiment that after the combination has taken place, the resulting volume of ammonia gas occupies, not 4 volumes, but only 2. In the same way 2 volumes of hydrogen when united with 1 volume of oxygen $(1 + 2 = 3)$, to form water vapour or steam, the volume occupied is 2 volumes, the same as the hydrochloric acid gas or the ammonia. It thus appears that when elementary gases enter into combination whether the combining volumes measure 2, 3, or 4, the compound gas which is formed only measures 2 volumes. We have already seen (248) that the molecular weight of any compound is always the sum of its component atomic weights, and hence, when in the gaseous state, it seems that the molecular weight of any compound gas always occupies the volume which would be occupied by 2 volumes of hydrogen, and hence it follows that *the density of any compound gas, when referred to hydrogen as unity, is equal to half its molecular weight.* Thus the molecular weight of hydrochloric acid gas is $35 \cdot 5 + 1 = 36 \cdot 5$, and its density is 18·25, or half this weight. The molecular weight of ammonia is 17, and its density 8·5. The molecular weight of steam is 18, and its density 9.

We have already seen (246) that an accurate analysis settles once and for ever the nature of the ingredients of any substance, but we now see further that it also settles at the same time the relative proportions, both by weight and volume, in which all the ingredients are always united. The service which

this knowledge renders to technology cannot be over-estimated, because in the preparation of the vast number of artificial bodies which are used in the arts, and in the chemical reactions which are daily used in all our large laboratories and dye-houses, it enables us to know exactly the relative quantities of different bodies which are required, so as to prevent on the one hand insufficiency, and on the other hand waste.

251. *Conditions of Chemical Combination.*—We have already seen (245) that chemical combination differs essentially from mechanical mixture, and, in the same way, no chemical combination can take place except under certain conditions, which differ widely from those which are necessary for mechanical action, or for the operation of such forces as gravitation or simple magnetic attraction. Both these forces operate upon masses of matter when at a sensible distance from each other, but chemical attraction never operates except when the matter is in such close proximity that, in most cases, at any rate, one of the bodies requires to be either in the liquid or gaseous condition, so that the parts of the matter come into molecular contact. In this respect chemical union is most like cohesion or adhesion, but it differs from these in that while they occur most powerfully between matter of the same kind, chemical union is always the most powerful and energetic when the substances entering into combination exhibit the greatest differences in their kind. In addition, cohesion and adhesion are always rendered less energetic by any rise in temperature, while a moderate elevation of temperature is usually favourable to chemical combination, and very frequently a result of it. In some cases of chemical action the temperature is lowered, but usually it is raised; and in every case, whether raised or lowered, it is always, for the same combination, a definite thermal change, and the number of heat units disengaged or absorbed is as constant as the combining weights of the bodies themselves. In addition to this, chemical combination

is, to use a figurative expression, *elective*—that is to say, that when a number of different substances are placed in conditions favourable for chemical union, any given element appears as if it had the power to choose which of the other bodies it would combine with, remembering however, that under the same circumstances it always chooses the same partner; and this power is so strong that one element will destroy the chemical union between others, in order that it may enter into combination with one or more of the constituents of the compound. This elective power is termed *chemical affinity*. It is upon this principle that nearly all our chemical reactions are based. We destroy weak combinations in order that we may form stronger, and the new compound is presented to us in some form in which we can separate it from the rest; or else we present to the substance operated upon a body with which one of its elements has a greater affinity, and the least strongly combined is rejected from the compound, and can then be obtained in its pure state. Thus, if we act upon water by metallic sodium, the affinity of the sodium for oxygen is so great that it destroys the union of the oxygen and hydrogen in the water, uniting with the oxygen to form sodic oxide, which is soluble, while the hydrogen escapes as a gas in the pure state.

252. *Chemical Affinity.*—From what we have already said, it will be seen that chemical attraction or affinity is the effect of a force or action the nature of which differs entirely from any of the forces which we have hitherto considered. Of its real nature we are quite ignorant: and in the present state of our knowledge in regard to chemical science, we can only conjecture what may possibly be its nature and cause; at the same time, it is quite necessary that we should have some definite idea or hypothesis in regard to it, because it will materially assist in the conception of the nature of matter, and of the changes which it probably undergoes when operated upon by force. We have seen that this force evidently

resides in the very nature of the matter itself, and cannot operate except at such short distances that the matter must be in the liquid or gaseous condition so as to bring the actual parts into contact. This indicates that before the affinity can be brought into play the parts of the combining bodies must be free to move, and it is therefore highly probable that this special property is in some way connected with the motion of the parts of which all matter is composed. These parts of each separate element may have a separate motion which is as distinctive as its specific properties, and indeed possibly the cause of them; and the recent researches in spectrum analysis give a high degree of probability to this supposition. The elective affinity may arise from some correspondence in the nature of the motions of two elements, while a compounding of the motions when two elements enter into combination would impress new properties on the resulting body. Our ideas of stability are not usually associated with motion, but we know that motion, as in the case of a gyroscope, confers a degree of stability upon the moving parts of the machine which cannot be otherwise attained, and the knowledge which we possess in regard to the probable nature of gases and the theory of heat, shows us that all matter is in incessant motion. This motion of the parts of matter is intimately associated with the most probable nature of its constitution, which is embodied in the *atomic theory*.

253. *Molecular Grouping.*—The constancy of chemical composition in the same substances, and the definite order of arrangement which is evident within the molecules of all bodies, as revealed by the constancy of quantitative proportion, suggest that there must be a regular arrangement in the parts of which all bodies are built up. In the gaseous and liquid state of matter, however, the cohesion of the parts and the regular play of the forces which seem to reside in the molecules of matter are broken by the action of the heat, which has separated the molecules from each other and thus broken up their arrange-

ment. In the solid state, however, we have this regularity clearly manifested, in the tendency which almost all solid bodies have when slowly formed out of their solutions to assume the forms of crystals. These crystals have always a definite arrangement of parts, which, however, differs in different directions; and hence, as we have seen (182, 201), crystals differ in their elasticity and power of transmitting light and heat in different directions.

The same substance may crystallize in a great variety of shapes, but these, when carefully examined, are always found to be slight modifications of a primitive or fundamental form, which is termed a *crystallographic system*. All solids may, when crystallized, be included under one of six different systems or their derivatives. These six systems may be termed:—

(1.) *The Regular System*, with three axes, all equal and at right angles to one another. (Fig. 78.)

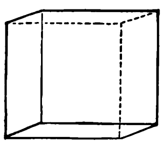


Fig. 78.—Regular System.

(2.) *The Hexagonal System*, with four axes, three equal and in one plane, making angles of 60°, and one longer or shorter, at right angles to the plane of the other three. (Fig. 79.)

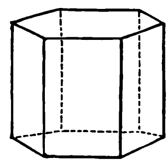


Fig. 79.—Hexagonal System.

(3.) *The Quadratic System*, with three axes, all at right angles, one shorter or longer than the other two. (Fig. 80.)

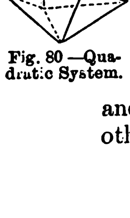


Fig. 80.—Quadratic System.

(4.) *The Rhombic System*, with three axes, all unequal and all at right angles. (Fig. 81.)

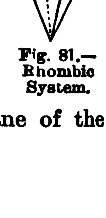


Fig. 81.—Rhombic System.

(5.) *The Monoclinic System*, with three axes, all unequal, two of which cut each other obliquely and one at right angles to the plane of the other two. (Fig. 82.)

(6.) *The Triclinic System*, with three axes, all unequal, and all oblique. (Fig. 83.)

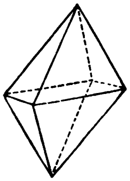


Fig. 82.—Monoclinic System.

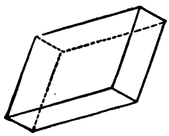


Fig. 83.—Triclinic System.

The figures given are only one out of many forms presented by each system, but will serve to show the general type. Bodies which exhibit similar chemical properties, and crystallize in the same forms, are called *isomorphous*. When the same body crystallizes in two different systems it is termed *dimorphous*.

CHAPTER III.

THE ATOMIC THEORY.

254. *The Atomic Theory.*—The laws of combining proportion are not hypothetical; they are the result of experiment, and indicate a real cause which springs from the nature of the elementary matter, whatever our ideas in regard to it may be. These laws reveal the fact that matter always enters into combination with other matter in certain fixed and definite proportions, which correspond to the specific gravities of the various elements when in a gaseous state, or in some simple multiple of these weights. In order to account for these phenomena, which were first clearly enumerated by John Dalton, he supposed that matter is not infinitely divisible, but that, just as in a compound body, we reach a point where we cannot further subdivide it, without destroying its specific properties; so, in the elements themselves, there is a point where no further division is possible, and we reach a minute portion of matter which has a definite size and

weight for each element, and which is the smallest part in which it can exist. These ultimate parts of the elements he termed *atoms*. The atoms, he supposed, have no parts, and therefore cannot be divided, and their weights bear the same relative proportions to each other that weights of equal volumes of the elements when in the gaseous state do to each other;—hence the term *atomic weights*, when applied to the combining proportions of the elements. For the same element, the size and weight of the ultimate atoms are absolutely the same, but both the size and weight differ in different elements. The hypothesis of atoms was not new as a speculation, because it was advanced as early as the days of the ancient Greek philosophers, but their supposition rested upon no experimental basis, while Dalton's views were deductions from actual observation. We have already seen (250) that when any two or more elementary gases enter into combination they always occupy the same space as that which would be occupied by twice the combining weight of hydrogen; and hence it is supposed that the atoms of hydrogen, even when in the pure state, are not free but combined two and two together, and form a compound body composed of two atoms of hydrogen. Any body which contains more than one atom, whether elementary or compound, is called a *molecule*, and hence the relative weight of this double volume of hydrogen is termed the *molecular weight*, to distinguish it from the single volume, which represents the atomic weight. In the same substance the molecule is always the same both in size and weight, but differs widely in different substances, both in the size, weight, and arrangement of its constituent atoms. When two bodies have the same chemical composition but differ in their properties, it is supposed the same atoms are differently arranged within the molecule. Such bodies are termed *isomeric*.

An atom, therefore, we consider to be the smallest portion of any element which can enter into chemical combination, and a molecule the smallest portion of any

substance, either elementary or compound, which can occur in the free state, or take part in any chemical re-action.

It is supposed that the smallest part of any substance, therefore, whether elementary or compound, is always present in the form of a molecule; and since all molecules of all substances, whether elementary or compound, when in the gaseous state, at the same temperature and pressure, always occupy the same space, it is inferred that their numbers always bear the same constant relation to each other, so that *the same number of molecules is always present in the same volume of gas at the same temperature and pressure.* This law is known as the law of Avogadro or Ampère, from the two distinguished physicists who first and independently enunciated it. From this law the two laws of Mariotte (133) and Charles (134), which we have already noticed, follow as a natural consequence, because if the same volume of all gases, at the same temperature and pressure, contain the same number of molecules, they will obey the same law of expansion by heat and of alteration in volume under pressure. In the same way, the relative weights of these molecules must be the same as the relative weights of equal gas volumes, because if in equal volumes there are equal numbers of molecules, each molecule of oxygen must weigh sixteen times as heavy as the hydrogen molecule, because the same volumes bear the same relative proportion by weight. It also follows that this relative weight and number of molecules gives a perfectly consistent explanation of all the observed laws of combining proportion, because when two elementary bodies enter into combination, they can only do so in the same numbers and proportions to form the same substances; and hence the law of constant proportion (247), because the atoms cannot be divided, and all possess the same weight for the same element. The atomic theory, therefore, accounts for the changes which take place in chemical re-actions between different bodies, by supposing a change of position to be assumed by the

atoms which form the molecules of the bodies entering into combination. When an element is set free from a compound, the liberated atoms join together to form molecules, unless some other body is present with which they can combine. This accounts for the fact that the elementary bodies always act most energetically just at the time they are set free from any combination, because the liberated atoms have not yet formed into molecules, and their affinities are therefore unsatisfied.

255. *Atomicity.*—We have already seen (249) that there is a difference in the power which the various elementary bodies possess to enter into combination in more than one proportion. There is also a difference in the power which they possess to replace each other in any molecular combination. The atoms of the various elements, therefore, the combining weights of which are expressed by the relative densities of the elements when in the gaseous state, exhibit very different values in chemical re-action. Thus an atom of zinc is equivalent to two atoms of hydrogen, because when zinc is brought into contact with steam at a high temperature, one atom of zinc expels from the steam two atoms of hydrogen, and occupies their place. When zincic oxide is brought into contact with hydrochloric acid the zinc is replaced by hydrogen, but two atoms are necessary to take its place. In the same way in combination, one atom of boron can replace three of hydrogen, one atom of carbon four of hydrogen, one atom of nitrogen five of hydrogen, and one atom of sulphur no less than six of hydrogen. This peculiar power of replacement in such different proportions is supposed to arise from the elementary atom possessing a certain form or a number of points of attachment, by means of which it can enter into combination with others, and thus an atom of oxygen, which can be replaced by two atoms of hydrogen, is supposed to possess two of these bonds, while hydrogen only possesses one. Just, therefore, as we can give to each

element a number expressive of the smallest weight with which it can enter into combination, we can also give to each a number expressive of its greatest atom-fixing power, or *quantivalence*, as it has been termed. The various elements are named *monads*, *diads*, *triads*, &c., as they possess one, two, three, &c., times the quantivalent power of a monad element. Hydrogen possesses the least quantivalent power, because it can never replace more than one atom of any element, while sulphur possesses the greatest, being able to displace in combination as many as six atoms of a monad, three of a diad, or two of a triad element. The elements which possess the same power of combining with the same number of hydrogen units, or its equivalent, can always replace each other in equal proportions. No element, either alone or in combination, can exist, except for a momentary period of time, with any of its bonds disconnected, and hence the elements themselves, when pure, have always the atoms united by their bonds as molecules, and the molecules of all elements with an odd number of bonds are generally di-atomic, or possessing two atoms in the molecule—as in the case of hydrogen—and always poly-atomic, or having more than one atom in them. Nothing whatever is known respecting the cause upon which this variation in quantivalence depends, any more than upon what the atomic weight depends, and we must always be careful to distinguish between what is theory and what is fact. Both atomicity and fixed proportion in atomic combination are, however, facts, whatever may be their explanation, and it is quite possible, indeed almost probable, that it depends in some way or other upon the atomic motions. We have seen from the phenomena of diffusion and expansion under increase of temperature in gases, that the component molecules of any gas are in a state of constant motion, and in the same way the atoms in the systems, which we called molecules, are most probably in continual motion, although the nature of this intermole-

cular motion is unknown. It cannot, however, be a motion of rotation, because the atoms evidently retain always the same relative arrangement or return to a mean position of equilibrium. The most probable supposition is that the motion of the atoms within the molecule takes place in straight lines, the atoms striking each other and then rebounding. What we call valency, or atomicity, may therefore be nothing but the number of contacts experienced by one atom on the part of other atoms in the same unit of time. In the same time that the monad atoms of a diatomic molecule like hydrogen come in contact once, the diad atoms of a diatomic molecule come in contact with each other twice, the temperature in both cases being the same. This difference in the atom-fixing power of the elements also brings into view the singular fact that the different atoms contained in a compound molecule are not kept together by the mutual attraction of the whole of the atoms upon each other, but that the atoms are arranged with regard to each other in a definite symmetrical order, the attraction acting only from atom to atom, and thus it is impossible to remove any atom without replacing it with one of equal valency, without destroying the equilibrium of the molecule.

256. *Size of Molecules.*—It may seem strange that the knowledge of the motion of the molecules in gases has enabled us to obtain a certain approximate knowledge of the size of the molecules of which they are composed. If we take a given weight of ice we can, by the application of heat, change it into water, which will occupy rather less space than the ice, and by a further addition of heat, convert the water into gas or steam, when it will, at the same temperature as the boiling water, viz., 212° Fahr., and under a pressure equal to thirty inches of mercury, occupy about 1,728 times the volume of the water; so that one cubic inch of water will yield about one cubic foot of steam. It is quite clear that in each of these states—ice, water, and steam—we have an equal

number of molecules. When in the state of a gas the molecules are at a considerable distance from each other and are flying about in all directions, the pressure on the containing vessel being the result of their impact, and the equality of pressure throughout all parts of the vessel, the result of the successive encounters or collisions of the molecules with each other. It is evident that the space in which the molecules can execute their evolutions is not the same as the total space occupied by the gas, since it must differ from that space by the total extent of the molecular volumes. The total size of all the molecules contained within the space, and the total space which intervenes between the molecules must, therefore, together make up the total gas volume. Now, if we can find in any gas how far one of the molecules moves before it comes into collision with any other—a distance which is called the *free path* of the molecule—we can calculate what space is occupied by the total mass of the molecules, and what by the intervening space between them, and we only then require to determine the number of molecules in a given volume to determine their size. Without entering into the means by which these various data have been ascertained, we may state, that at the temperature of freezing water, and the pressure of thirty inches of mercury, the mean free path of a molecule of hydrogen gas is about the one-fifth part of the wave length of a ray of green light, which is about $\frac{1}{47,500}$th of an inch, so that the free path of the hydrogen molecule is $\frac{1}{237,500}$th of an inch. The hydrogen molecule has the longest free path of any known gas, and probably, therefore, is also the smallest in size, as it is also in weight. When any substance is in the state of a liquid it is found that it can be compressed very little, and hence the molecules when in the liquid condition are supposed to be as close together as they are at the instant of collision when in the gaseous state. The difference between the space occupied by any body, therefore, when in the liquid and gaseous condition, gives us an approxi-

mate idea of the relative volumes occupied by the total number of molecules, and the space between them when in the state of gas. These relative volumes and the free path being known, it is only a matter of calculation to determine approximately the number of molecules which must be present in any gaseous volume, and the size which they probably possess. The results thus obtained from dynamical considerations have been checked by various other methods, such as the stretching of a film of soap and water, and the mechanical work accomplished by contact electricity produced by plates of zinc and copper; and it appears that, as a rough estimate, made by Sir W. Thomson, the size of the molecules of matter is not larger than the $\frac{1}{250,000,000}$th of an inch or smaller than the $\frac{1}{5,000,000,000}$th of an inch, so that if we could magnify a single drop of water $\frac{1}{8}$th of an inch in diameter until it looked as large as the earth, and if each molecule were magnified to the same extent, the molecules would not look smaller than small shot or larger than a cricket-ball. About one hundred thousand million billion of molecules are contained in a cubic inch of hydrogen gas, when the thermometer is at the freezing-point and the barometer at 30 inches. Two hundred million billion of these hydrogen molecules only weigh one milligramme, which is equal to 0·0154 of an English grain. These quantities are absolutely inconceivable to the mind, and are only very rough approximations, but they serve to show that our notions of the elementary atoms and molecules are of a definite character, and perhaps as distinct as the immense distances revealed by the science of astronomy. It has also been found that in refracting bodies which bend a ray of light, although there might be refraction, there could not be dispersion unless the size of the molecules and the distance between the molecules of the body bear a sensible relation to the wave lengths of the light itself, and that the dispersion of white light into colours through a prism could not be what it is if the distances of the molecules were much greater than the $\frac{1}{10,000}$th

part of a wave of light, the average length of which may be taken as about $\frac{1}{45,000}$th of an inch, so that the molecules are probably not farther apart than about $\frac{1}{450,000,000}$th of an inch, and this distance, therefore, limits the size of the molecule.

257. *Nature of Atoms.*—The nature of the ultimate atoms has always been a subject for speculation, and remains so still, because we have absolutely no experimental data upon which to work. Newton suppcsed them to be massy, hard, impenetrable, indivisible, and indestructible, and of various sizes and figures corresponding to the different elements. Other philosophers have endowed them with the same qualities, and pointed out that there is not a regular gradation in the mass of these atoms from that of hydrogen, which is the least up to that of bismuth, which is 210 times as heavy, but that they fall into a limited number of classes between which there are no intermediate forms, and every individual of each class is of exactly the same magnitude, and, like pendula of the same length, vibrate in exactly the same time when in a state of motion. Clerk Maxwell says "They agree in the nature of the light which they emit—that is, in their natural periods of vibration, and they are, therefore, like tuning forks, all timed to concert pitch, or watches regulated to solar time." The difficulty of conceiving that matter in any form could be so absolutely unalterable throughout all time, and that the material nature of the atoms is a philosophical truth rather than a hypothesis, led Boscovich to suggest the idea that atoms are not solid particles but only mathematical centres, from which proceed forces which at small distances are attractive, at certain other distances repulsive, and at greater distances attractive again. This theory, although it satisfies many mathematical requirements, presents so many difficulties in regard to the nature of the properties experimentally exhibited by matter that it is not now accepted, and those who reject the idea of hard and indestructible solid

atoms adopt the theory which is now known as that of *vortex atoms,* which we may term the *dynamical theory of matter.* A vortex ring is simply an eddy such as that seen upon the surface of a fluid when a solid is drawn through it; but in this case the fluid has a free surface, so that the vortex ring is seen in section at the two free ends. If, however, the ring is formed in a fluid, such as air, which has no free surface, the ring is continuous and without free ends, so that it forms a self-contained equilibrated system.

258. *The dynamical theory of matter* supposes that the ultimate atoms are nothing more than a vortex motion formed in the all-pervading ether of space, and that the nature of these motions determines the specific character of the atoms. It has been found that if a vortex ring is formed in air, which has been rendered visible by smoke, it will move freely through the surrounding air, so that the entire mass of smoky air which forms the ring revolves continually round a circular axis, which forms the nucleus of the ring. In this ring all the particles which are situated upon one of the curves, which can be drawn in each section of the ring, are absolutely tied down to their circular paths, and can never quit them so long as the ring exists, so that the ring is always formed of the same molecules, and moves through the surrounding air as if quite distinct from it. This ring cannot be broken, and hence is indestructible; and if it is brought into contact either with another ring or any other body, the ring's path is changed and the ring simply is thrown into vibration, but retains its form and independent motion, its parts oscillating about their centre of equilibrium. Helmholtz, who mathematically analysed the conditions of vortex motion in a frictionless fluid, proved that in such a medium vortex rings, bounded by a system of vortex lines, are always formed of an invariable quantity of the same molecules, so that the rings can move and change their parts without any destruction—that is to say, without their ring-form ever being broken. In such

a medium, also, he proved that, when once formed, they would always retain their individual character unchanged, so that they would continue to revolve and remain separate and indivisible for ever. Such rings may have any number of twists, and even pass through each other like links in a chain; but once formed, they will retain their peculiarities of motion and linkings for ever. According to this view, all the elements are formed of special vortex rings, each of which, by its peculiar motion, impresses on the element the special characteristics which it possesses; for the same element the motion is absolutely the same, and from its very nature invariable and indestructible. When entering into combination with other atoms, it does so as an absolutely distinct and indivisible unit; and when its motion, which is constrained or rendered rhythmic by the proximity of the motion of a different atom is freed by decomposition, it re-assumes its original form and original properties without any possible change or diminution. The ether is in fact, on this hypothesis, the only fixed element in nature, and what we term material bodies are only differentiated portions of the ether which move and vibrate in this all-pervading medium. Such a hypothesis—for it is nothing more, and at present our knowledge in regard to vortex motions is only small and confined to circular forms—supplies a satisfactory explanation of some of those essential properties of matter which are so difficult to conceive in regard to solid atoms, and the unity which it gives to our views of the relations of matter and force renders it increasingly acceptable as a possible solution of the difficulty in regard to atomic constitution.

Part VI.

THE CONSERVATION OF ENERGY.

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259. *The Doctrine of the Conservation of Energy* will always mark the nineteenth century in the history of discovery, and is undoubtedly one of the greatest and grandest generalisations of modern science.

It has already been shown that all of the physical forces, such as heat, light, electricity, or magnetism, are capable of being transformed into each other, and also that each of them can be made to perform mechanical work by the communication of motion to matter. All these various manifestations of force are, however, only modes or conditions of one universal energy, which underlies all the changing phenomena of the universe. This energy may be active or passive, it may be diffused or concentrated, it may assume unnumbered forms and guises, but it is one in its essential nature, and the sum of all the various forms of energy in the universe, when measured by their capacity to do work, is always a constant quantity.

It is in the ceaseless transmutation of energy from one form to another that the myriad phenomena of the universe are manifested, and in their fleeting passage we obtain the power which can drive our machines, and do our work. In the midst of this constant flux, however, there is no loss and no gain. Every disappearance of energy in an active form is always accompanied by an equivalent amount of work performed, and the doctrine of the conservation of energy simply means, that when this work is undone, or the machine worked backwards,

we always find liberated, for the performance of other work, exactly the same quantity of energy which had disappeared when the original work was done. Heat may be changed into light, light into chemical action, chemical action into electricity, electricity into magnetism, magnetism into mechanical motion, and mechanical motion into heat again; and in the whole series of changes, if it were possible to register exactly the amount of work done during each change, we should find no loss and no gain, and the final quantity of heat, when measured by the mechanical work which it could perform, would be identical with the same number of heat units with which the series was commenced.

It is not easy to realise the various steps by which this principle of the conservation of energy was gradually arrived at, or the nature and variety of the proofs by which it is now sustained. It is also equally impossible to over-estimate the great importance of the discovery, and the definiteness which its adoption has introduced into every department of science.

260. *Definition of Energy.*—Energy may be defined as *the power to do work,* quite independent of the special form or mode in which it may be stored, or the character of the manifestation which it will exhibit during the performance of the work. Whenever energy changes its condition it always does work, and whenever work is done, whether it is visible or invisible to the senses, an equivalent amount of energy disappears.

261. *Dynamical Unit.*—Work is said to be done by energy or one of its special forms whenever resistance is overcome. The measure of the resistance which is overcome by any force, or the amount of work which is performed, is in this country measured by the amount of matter which can be raised against the force of gravity to the height of one foot, if the energy be continuously exerted during one minute of time. The standard measure of the quantity of matter being the pound weight, we measure the effect of any force by the

number of pounds which can be raised one foot high in one minute of time. This measure is called the foot-pound, and constitutes the dynamical unit.

Thus we have already seen (111) that our term horse-power really means the power which, continuously exerted during one minute of time, would exactly raise 33,000 pounds one foot high.

262. *States of Energy.*—Energy has already been spoken of as active or passive (259). By this we mean that energy may either be in the act of doing work, or stored up in some form, such that, under suitable conditions, it may be liberated so as to enable it to do work. Stored energy is always spoken of as *potential energy*. We have an instance of this stored or potential energy in the mechanical force which is stored up in a clock weight or mainspring of a watch, which is gradually liberated as the clock or watch runs down, or in the chemical force of dynamite which is instantly set free when the dynamite is exploded.

When energy is liberated, and performing work, it is called *kinetic or actual energy*, because the work is no longer stored but in the act of being expended on work. We have an example of this form of energy in the motion of a cannon ball which is being gradually brought to rest by the resistance of the air, or the falling clock weight, whose energy is being expended in driving the works of the clock. These two states of energy, although they are widely different in their character, are easily changed from one state into the other, and all the phenomena of the physical universe are really the result of this change which is continuously in operation.

263. *Classification of Energies.*—Without a much more thorough knowledge of the relation of force to matter, and of the nature of matter itself, than is possessed at the present time, it is quite impossible to give anything but a very incomplete view of the various forms of energy which are presented to us in the universe.

Incomplete, however, as any classification may be, it will enable us to systematise our thoughts and ideas in regard to it. We may therefore divide the various kinds of energy as follows :—

A. ENERGY OF MASS.—Gravitation.

I. *Visible Potential Energy.*—A raised weight.
II. *Visible Kinetic Energy.*—A falling weight.
III. *Visible Potential and Kinetic Energy.*—A swinging or vibrating pendulum.

B. ENERGY OF MOLECULES, OR MOLECULAR SEPARATION.

IV. *Invisible Potential Energy.*—Any confined volume of steam.
V. *Visible Kinetic Energy.*—Condensing steam, or the recoil of a bent spring.

C. THERMO-ENERGY, OR ABSORBED HEAT.

VI. *Invisible Potential Energy.*—Latent heat.
VII. *Visible Potential Energy.* — Expansion of bodies when heated which can do work on cooling.

D. ELECTRICAL ENERGY, OR ENERGY OF ELECTRICAL SEPARATION.

VIII. *Invisible Potential Energy.*—A charged Leyden jar or voltaic battery, with interrupted circuit.
IX. *Visible Kinetic Energy.*—An electric current fusing a wire or driving an electro-motor.

E. CHEMICAL ENERGY, OR ENERGY OF ATOMIC SEPARATION.

X. *Invisible Potential Energy.*—A mass of gunpowder or nitro-glycerine.
XI. *Visible Kinetic Energy.*—The burning of fuel attended by light and heat.

F. RADIANT ENERGY.

XII. *Invisible Potential Energy.*—Any heated or incandescent body.

XIII. *Visible Kinetic Energy.*—A ray of light. The latter may also be considered as partly potential and partly kinetic, because in all undulating media there is a period of rest which marks the amplitude of the vibration.

Before we can pass on to the consideration of the relation of these various forms of energy to each other, we must look at them each a little more in detail.

264. (A) *Energy of Mass.*—Every mass of matter in motion possesses visible kinetic energy, and is therefore capable of performing work. This is exhibited in the universe on the grandest scale in the motions of the heavenly bodies, such as the planets round the sun. On the smaller scale it is also manifest in the constant ebb and flow of the tides, or the action of gravitation which sets in motion all bodies which are free to move from a higher to a lower level. If a weight be projected upwards, evidently the moment the projecting force ceases to operate, it contains stored up within itself a quantity of power which enables it to continue rising against the force of gravitation. As it continues to rise, however, it is thus continuously performing work, and finally is brought to rest at that point in the air immediately before it begins to fall again.

The kinetic energy of the moving weight is at this distance from the earth evidently all expended, because it ceases to move; and if some permanent support is placed immediately beneath the weight, such as a ledge on a high building or tower, it will remain at rest for any length of time. Although the ball would be at rest, however, gravitation, which produced the state of rest, would still be acting upon it; and it is quite clear that *it would* then be in a new condition, because, while it

was ascending and doing work against the action of gravitation, it was gradually being separated farther and farther from the gravitating centre, and might therefore at any time, by the removal of the support, be made to fall again, when its capacity to do work would be restored. The kinetic energy which the ball received from the original impulse which projected it upwards has, in its state of rest, become potential; and as the reason why this energy has assumed this condition is because a new position is taken up in regard to another mass of matter, we may term this state of potential energy, *energy of position*. When this energy of position is again changed into kinetic energy by the fall of the body, the accumulated work which has been stored up in the body is proportional to the mass of the body which is its weight in pounds, and to the square of the velocity with which it is moving. The velocity is measured by the number of feet through which it is moving in one second of time. For example, a body weighing 100 lbs., and moving with a velocity of 1,000 feet per second, would possess a kinetic energy capable of doing 1,552,795 units of work, because we have $\frac{100 \times 1{,}000 \times 1{,}000}{64 \cdot 4} =$ 1,552,795 where the divisor 64·4 is twice the velocity impressed on a falling body by the action of gravity in one second of time.

265. *Energy of Mass and Momentum.*—It is a common mistake to confound the two distinct ideas of kinetic energy and momentum. They are, however, fundamentally different, and are therefore measured by a different unit. The unit of momentum is one pound, moving with a velocity of one foot per second. The unit of force is that force which, acting for one second of time, produces in the unit of mass a velocity of one foot per second. Momentum is simply the total quantity of motion which is possessed by the moving body, and increases in arithmetical progression as we increase the velocity or the weight of the body. If we double the weight the momentum is doubled, and in the same way

if we keep the weight constant and double the velocity we double the momentum. The kinetic energy or power to do work, however, rises with geometrical progression and takes no consideration of the momentum of the body, but simply the power which the body in motion possesses to do work against opposing forces. For example, if we employ a minute of time as the period during which our unit of force operates on a body instead of a second, we shall augment our momentum sixty-fold, because the minute contains sixty seconds. In regard, however, to the kinetic energy the case is different. What we formerly called our unit of force was that which, acting only for one-sixtieth of our new unit of time, produces in a mass of one pound sixty-fold the new unit of velocity, so that the kinetic energy, or power to do work, is increased three thousand six hundred-fold.

266. (1) *Visible Potential Energy.*—In looking at the action of a mass of matter, when doing work against the force of gravitation, we have already seen that when the motion becomes arrested by its upward flight, we have an instance of kinetic energy, which originally impressed the motion upon the mass, becoming potential by its capability of giving out the original kinetic energy when permitted again to fall to the position from which it was originally removed. This visible potential energy is only a type of the stored energy of the universe, upon which all its phenomena depends.

Thus, in the distances of the planets from their central suns, or of the various sidereal systems from the grand centres towards which they gravitate, we have on the large scale a store of energy which is practically unlimited. On our own earth we have similar instances in a stone on the top of a mountain, or the water stored in a mountain lake, or in our machines in raised weights or compressed springs.

267. (2) *Visible Kinetic Energy.*—When a raised weight, which has been at rest, commences to fall again, as we have already seen, its potential energy is changed

into kinetic energy. This is also only a type of an immense quantity of this energy which is visible in the universe around us. We have it in the motions of the planets, in their orbits, and in their rotation; also in the motions of the various sidereal systems, and the slowly concentrating masses of the nebulæ. We see it in the rising and falling of the tides, in the flow of rivers, or in the winds which sweep over the surface of the earth. In our machines, we behold it in the rush of the locomotive with its heavy train or the ponderous momentum of the fly-wheel of a stationary engine. In the heavy blows of the tilt hammer, the motion of a steamer against wind and tide, or in the flight of a cannon-ball from the mouth of a heavy gun.

268. (3) *Visible Potential and Kinetic Energy.*—Under certain conditions the energy possessed by a moving mass of matter may be continually changing from the potential into the kinetic form, and *vice versâ.* We have an example of this in the motion of a pendulum, where it swings from a position of rest at the turning-point of its range of vibration, through an intermediate stage of motion to another position of rest at the other extremity of its range. This alternation of motion and rest is indeed characteristic of all vibrating bodies, and we have a good example of it in the energy possessed by waves of sound, where the alternate expansion and compression of the air arise from an excursion of the aërial molecules from a state of rest to a state of motion and back again.

269. *Various Forms of Energy.*—So far we have only considered the various forms of energy which are visibly manifested either in the motion of masses of matter or in the potential form in the arrangement of matter, under such conditions that the production of energy from its motion is evident to the unaided senses. There are, however, many forms which energy may assume where its existence, or the evidence of it, is not so distinct, but where it is equally present, and can be made evident by suitable means and instruments.

270. (B) *Energy of Molecules, or Molecular Separation.*—This form of energy is stored in or liberated from combinations of molecules which are themselves formed of systems of atoms. It is less energetic than chemical energy, and is, indeed, another form of energy of position, arising as it does from an interval of space existing between the molecules which form the structure of matter, whether in solid, liquid, or gaseous condition. It may be stored in the potential form by the mechanical act of the separation of the molecules, as in a bent bow, and become kinetic in the flight of the arrow, but it is much more frequently the result of the action of absorbed heat, which forces asunder the molecules to a greater distance from each other, and becomes visible in the expansion of the mass, quite independent of the vibratory motion which the heat induces in the molecules themselves. The work accomplished is really the overcoming of the cohesive attraction of the constituent parts of the body, and is sometimes called molecular or cohesive energy. We have a good illustration of it in the potential energy stored in steam, which is only molecules of water whose cohesion has been overcome by the action of heat, and when this cohesive energy again comes into play by the diminution of volume during condensation, we have the energy again becoming kinetic and capable of performing work.

271. (C) *Thermo-Energy or Absorbed Heat.*—This is the energy possessed by a hot as distinguished from a cold body, and may, as we have already seen, be regarded as a peculiar motion imparted to the molecules of a body as distinguished from a cold body where this motion is absent. It may be communicated to another body by direct contact with it, in which case it performs intermolecular work by increasing the volume of the warmed body, or it may communicate motion to the surrounding luminiferous ether, in which case it assumes the form of radiant heat, which differs entirely from absorbed heat. *Within* the molecular system of a body it may perform

two distinct classes of work. The first of these classes is, as we have already seen, molecular separation, which may, in the case of steam, be measured by the latent heat, while the other work which is molecular motion is measured by the absolute temperature. Thermo-energy is potential in all bodies which are warm, and becomes kinetic whenever this warmth or heat is permitted to diffuse itself into any colder body.

272. (D) *Electrical Energy, or Energy of Electrical Separation.*—This energy is also probably a peculiar motion, or molecular strain, arising from the attraction which heterogeneous atoms possess for one another. In this sense, therefore, it is only another form of energy of position. It is potential in the form of electrical separation or magnetism, and kinetic in the form of a current or molecular motion, when the molecular equilibrium of a system or body is being re-established. We have an instance of the former in a charged Leyden jar, and of the latter in the spark which springs from one point to another when the circuit between the two surfaces is completed.

273. (E) *Chemical Energy, or Energy of Atomic Separation.*—Gravitation is the attraction which masses of matter as a whole possess for each other, and atomic or chemical energy is the attraction which the ultimate atoms or smallest units of matter possess for each other. It is really a special form of energy of position, similar to a raised weight, only the attracted and attracting bodies are much more equal in size, and the attraction much more powerful than gravitation, which is relatively a weak force. This energy is stored, and becomes potential whenever these affinities are overcome by the action of any energy capable of dissociating the atoms, as in the decomposition of water into oxygen and hydrogen under the action of an electric current. It becomes kinetic whenever the affinities are exercised and the atoms enter into combination, as in the explosion of oxygen and hydrogen when water is formed, or of gunpowder when a light is applied.

274. (F) *Radiant Energy.*—This is the energy which is stored in all bodies whose atomic or molecular motion is capable of communicating motion to the ethereal medium, which we have already seen pervades all space. It is kinetic in the motion or disturbance of the equilibrium of the ether, whether the motion which the ethereal medium is capable of communicating to matter takes the form of heat, light, actinic action, or electrical separation. The best instance which we can give is solar radiation which, when it falls upon matter, heats and illuminates as well as induces chemical action and decomposition. This last is clearly seen in the photographic action of sunlight, or the power which the leaves of plants possess under its influence to tear asunder the atoms which form the molecule of carbonic acid.

275. *Transmutation of Energy.*—Although the various forms of energy are essentially different in their manifestations, they can, nevertheless, under certain conditions be very readily changed or transformed into each other. To change into or reproduce from some of the special forms of energy any other particular form, it is, however, often necessary to cause the original energy to pass through several intermediate forms before the final change is reached. The following are a few of the various instances in which energy of one form can be changed into energy of another form.

276. Potential Energy of Mass may be changed into—

1. *Mechanical motion*, or kinetic energy of mass, as in a falling weight where the energy is visible and kinetic.
2. *Thermo-energy*, or heat, if the falling body is permitted to stop suddenly by impact against another body when both are warmed; or if the energy of the falling weight be expended on producing friction, either in solids or in liquids, as in Joule's arrangement of paddles.
3. *Molecular energy*, if the heat of friction in the liquid is continued until steam is raised.

4. *Radiant energy*, if the absorbed heat or molecular energy of the solid or liquid warmed by friction is permitted to radiate into space.
5. *Electrical energy*, if the radiant heat is permitted to fall on to a thermo-pile, and thus produce the energy of an electric current.
6. *Chemical energy*, if the electric current is used to decompose water into its constituent gases.

277. KINETIC ENERGY OF MASS may be changed into—

1. *Visible potential energy*, if the moving weight is employed to raise another weight, as when the full trucks in a colliery incline raise the empty ones to the bank again.
2. *Thermo-energy*, if the moving body is permitted to impinge upon another body, such as a cannon-shot against a target, when both target and ball become heated.
3. *Molecular energy*, if the body is fused by the impact or by the friction of a resisting medium, as many meteorites, on entering the atmosphere, out of space.
4. *Radiant energy*, as when the blow or impact produces a flash of light.
5. *Electrical energy*, when the falling weight drives a magneto-electric machine, and thus produces an electric current.
6. *Chemical energy*, when the heat of friction produced by the moving body causes chemical action, such as in the striking of a lucifer match or percussion fuse of a shell.

278. ENERGY OF MOLECULES, OR MOLECULAR SEPARATION, may be changed into—

1. *Visible kinetic energy*, as in the expansion or condensation of steam.
2. *Visible potential energy*, as when the steam, either by condensation or through a steam-engine, raises water to a higher level.

3. *Thermo-energy*, as when the latent heat is given out by condensing steam.
4. *Electrical energy*, as when a steam-engine drives a dynamo-electric machine, and thus produces a current.
5. *Radiant energy*, where this current produces the electric light.
6. *Chemical energy*, when this current fires gunpowder or produces chemical decomposition.

279. Thermo-Energy, or Absorbed Heat may be changed into—

1. *Molecular energy*, as in the production of steam.
2. *Visible kinetic energy of mass*, as in the rotation of the fly-wheel of a steam-engine.
3. *Visible potential energy of mass*, as when the steam-engine is employed to raise the weight of a pile-driving machine.
4. *Electric energy*, as when the steam-engine actuates a dynamo-electric machine.
5. *Radiant energy*, as when a hot body cools by radiation into space.
6. *Chemical energy*, as when heat produces chemical decomposition.

280. Electrical Energy, or Energy of Electrical Separation, can be changed into—

1. *Visible potential energy*, as when an electro-magnet raises and supports a weight.
2. *Visible kinetic energy*, as when an electric current drives a reverse dynamo machine, or any electromotor, as in the electric railway.
3. *Thermo-energy*, as when the current raises a platinum wire or ribbon of carbon to incandescence.
4. *Molecular energy*, as when the current fuses a wire and raises the metal into vapour.
5. *Radiant energy*, as in the electric light.
6. *Chemical energy*, as when the current decomposes any electrolyte.

281. Chemical Energy, or Energy of Atomic Separation, may be changed into—

1. *Visible kinetic energy*, as when a shot is discharged from a cannon by the explosion of gunpowder.
2. *Visible potential energy*, when any explosion raises a mass of matter to a higher level, as when the weight of a pile-driving machine is raised by explosion.
3. *Thermo-energy*, in any chemical combination which disengages heat, as in ordinary combustion.
4. *Molecular energy*, in the condensation of any gas by its own pressure on liberation from combination, as in a gazone or soda-water machine.
5. *Electrical energy*, as when an electric current is produced from a voltaic cell, by the action of an acid upon a solvent metal.
6. *Radiant energy*, as in the production of light by combustion in a candle or lamp.

Many other illustrations of the transformation of energy might be mentioned, but the above examples are sufficient to show that all forms are interchangeable.

282. *Quantivalence in the Transformation of Energy.* —The doctrine of the conservation of energy requires that all the changes which energy can undergo take place without any loss or gain, and that when any transformation takes place, if all the effects produced are taken into account, they are exactly equal to the original amount. When matter undergoes transformation into a new condition, as in chemical synthesis or analysis, we can bring all the resulting substances to the test of the balance, because the refinements of modern chemical manipulation enable us to reduce the loss of matter to an almost inappreciable quantity, so that the indestructibility of matter can be physically demonstrated to the senses. In the transformations of force, however,

have an imponderable agent to deal with which can diffuse itself in a large number of ways, so that it often becomes a physical impossibility to account for all the original force, and with our best experimental results we can never absolutely change all the energy in one form into that of another. This tendency on the part of energy when undergoing transformation to assume forms in which it cannot be reproduced in the kinetic form is called the *Dissipation of Energy.* We have an illustration of this in the running down of a clock-weight where the energy is expended on the friction of the machine, or the motion of the air in the ticking of the escapement or the striking of the bell, which can never be recovered again.

The truth of the doctrine of the conservation of energy, however, rests upon rigid experiments and just in proportion as our experimental and instrumental means become more perfect we are able to prove more and more definitely the quantivalent nature of every transformation. The researches of Joule, which we have already mentioned (205), on the transformation of mechanical work, such as the energy of a falling weight, and of chemical and electrical energy, into heat; and of Thompson, Rankin, Clausius, and others on the transformation of heat into mechanical work have settled the question beyond all doubt. They have proved that whenever mechanical work is performed by the agency of heat, the same quantity of heat always disappears and passes out of existence as heat, whenever the same quantity of work is performed, and this constant relation is, as we have already seen, called the mechanical equivalent of heat. The same quantivalence also holds good between heat and molecular work, or molecular separation, as in the expansion of gas of the same kind under similar conditions of pressure, also in the production of electrical currents in a thermo-pile, or the reverse process where electric currents are made to heat a wire. It also holds good that a given quantity of chemical action, as

measured by the solution of the positive element in the electrolyte, always reproduces an equivalent quantity of chemical decomposition or recomposition, such as in electro-plating in any other electrolyte when the circuit is closed.

Nothing proves the truth of a theory better than the power to predict phenomena which have not yet been observed, but which must occur if the theory be true. The application of this doctrine of the conservation of energy has enabled us to foretell certain results which were unexpected except as a result of this theory, and when tried experimental confirmation was obtained: such as the lowering of the freezing-point of water by pressure, or the cooling of any substance by compression which contracts by the application of heat, such as water between about 32° Fahr. and 39° Fahr., or Indian rubber which is heated by extension.

283. *Law of the Conservation of Energy.*—If we therefore separate a fixed and definite portion of the energy of the universe, or at any rate conceive of its being so isolated, for it cannot actually be accomplished, whatever changes and transformations it undergoes, we know that the sum of the mechanical work which all the several energies are capable of performing is always a constant quantity. Some of the energy may be potential and some kinetic, but the sum of the two in whatever form they may exist is always the same. They may exist as energy of mass, as absorbed heat, as molecular or electrical separation, as radiant energy or chemical or atomic separation; but the sum of the whole, when measured by their capacity to do work is always constant. The relative proportions of each may vary every instant, and, indeed, some of them may disappear altogether, but only to increase the quantity of the remaining forces, and amidst all the transformation the sum total never varies. The great Faraday thought that this law of the conservation of energy was violated by the increase in attractive power, which all bodies experience as they approach each

other, and which is inversely as the square of the distance. He even went so far as to endeavour to determine, but without success, what became of the energy of attraction which was lost when two bodies were separated from each other. We must, however, remember that this gain in attraction when bodies approach, and loss when they recede, is really only the loss in kinetic or gain in potential energy, which was originally expended in the diffusion or separation of matter, and that the law of gravitation itself is a mathematical deduction from the theory of the conservation of energy.

284. *Dissipation of Energy.* — Although the two states of energy—potential and kinetic—are mutually interchangeable, so that potential energy of mass may be changed into kinetic energy of motion of the mass, still there is a physical limit to this change, because kinetic energy may be expended in the performance of molecular work where the motions are too small to be recovered again as potential energy of mass (282). It has been experimentally proved—and in strict accordance with theory—that although it is quite possible to change all the stored energy of a mass of matter, when liberated by its motion, into heat, it is not possible to reverse the process and change all the heat back again into mechanical motion. There is always a certain portion of the heat frittered away, disappearing in the performance of work amongst the molecules of matter, and which cannot be recovered by any means at present known to science.

The gradual concentration of all the matter in the visible universe, which is evident in the past history of our solar system and in the star clusters and nebulæ in the far-distant regions of space, is therefore slowly changing all the potential energy which was originally present in the universe into the kinetic form. This process undoubtedly points to an end to all its phenomena, unless there is some higher and exterior law in operation with which we are not at present acquainted. *The ultimate* form to which the kinetic energy of the

universe tends is diffused heat, and when this long-protracted diffusion will have been accomplished, so that all matter will possess a uniform temperature, all motion and all life will cease. Millions of years, countless as the sand upon the sea-shore, will roll away before this end will come, but come it will as surely as a clock will run down if no exterior power raise the fallen weight.

We may also point out that this same law also indicates a beginning, because the sum of the potential and kinetic energy being a constant and finite quantity, the phenomena of the universe cannot have been exhibited from all eternity, or else the potential energy would all have assumed the kinetic form. How distant the time of the beginning may be no computation can determine any more than it can determine the time of the end; but that there has been a beginning, and that there will be an end, to the existing condition of the universe, is as certain a deduction from the present knowledge of physical causes, as any knowledge which we possess.

The dynamical theory of matter opens up a wide field for speculation as a possible source of unexhausted energy in the universe; but into this question the limit of our work forbids us to enter. Let it suffice to say that we are probably only on the threshold of our knowledge of the physical universe and its laws, and that each step which we take, while it may widen our knowledge, only reveals a still wider region into which it is difficult but probably not impossible to enter. Guided by the laws which have been ascertained from rigid observation and experiment, we may rest satisfied that each step forward will be followed by increased power on the part of man to control the forces and reactions of the material world, so that in the future, as in the past, the progress of science will be at once a cause and a proof of an advance in civilisation and will thus confer measureless benefit on mankind at large.

INDEX AND GLOSSARY.

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EDITED BY

PROFESSOR AYRTON, F.R.S.,

AND

RICHARD WORMELL, D.Sc., M.A.

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The numerous Illustrations to these books will be pictures of the actual machines as they exist in the best factories, and will not be merely conventional representations conveying but little intelligence to the practical man.

The aim throughout has been to prepare books that shall appeal at once to the workman. Their preparation has been entrusted to writers who know what the workman's difficulties are, what information he needs to help him in his trade, and this is presented in such a form that the reader may be attracted by a desire to learn the Why and Wherefore, instead of being repelled by the supposed difficulties of science.

CASSELL, PETTER, GALPIN & CO.: LONDON, PARIS & NEW YORK.

(*List continued on next page.*)